Working Paper Series No. 19

Standards of Today – Innovation and Interoperability

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21 April 2017

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1. Introduction

In the not too distant past, standards were seen as technical issues to be left to committees and R&D departments. These groups worked on safety and quality standards to assure consumers that products were reliable and ensure that products like plugs and screw threads from different manufacturers could be used together. Things have moved forward. Today, standard setting in some industries is an increasingly complex affair and is often central to business strategy and policy. In fact, in some industries like mobile communications, standards setting is a misnomer. What is involved is technology development that aims at massive improvements in performance. This technology then gets encapsulated in a standard. Put differently, the activity is more properly thought of as technology development for standards (or standards development). Standards ensure the interoperability of major networks in industries such as information and communications technology (ICT) and also coordinate the innovation of new systems technologies. Being accepted as an industry standard may be the single most important factor in the success of a new technology, and vice versa. Products not conforming to the standard may not find a market, and a standard not supported by leading technology may not get adopted. The licensing of standards-related IP has become big business, and often the subject of lawsuits and regulatory intervention.

In this chapter, Section 2 discusses the way standards setting combines two main functions: to ensure interoperability between products from different firms and to coordinate the development of new technology. It describes how standards add value, reviews characteristics of different types of standards, and describes mechanisms to focus technologies and agree standards. Some standards rely mainly on market forces to establish a leading standard; others require increasingly close collaboration across an industry via a variety of standards organizations. The section distinguishes different types of standards organizations suited to the particular needs of the standards. It then considers what makes some standards more successful than others and strategies that firms may follow to establish standards and optimize returns. It details some steps sponsoring firms may take to ensure an appropriate return from their development efforts so that benefits do not just accrue to implementers and consumers, but also provide incentives to developers. The idea of balance between the returns to the various parties (developers, implementers, service providers, and customers) runs through standards strategies, policies, and regulations.

Sections 3 through 5 present three case studies illustrating different aspects of standardization. The first example reviews recent electrical connector standards. These illustrate a traditional function of standards to define compatibility specifications from alternatives whose technical differences may be important but which add value largely from commonality and convenience. The second example reviews the standards contests in video cassette recorders (VCRs) in the 1970s. It identifies important market-based strategies used to ensure wide support for a new standard, shape standards dynamics, and win contests. The third example describes the development of recent standards in Wi-Fi and mobile communications. These depend centrally on formal and informal standards organizations to coordinate global standards among firms across major industries. Section 6 reviews some potential future standards directions.

2. The Role of Standards

2.1 How standards add value – interoperability and innovation

There are many types of standards. Standards have been vital in the introduction of some of the most significant innovations of recent years, such as the video cassette recorder (VCR), personal computer (PC), computer memory, and mobile communications. Despite the many millions of R&D dollars spent, standards have also contributed to some major product disappointments, such as digital audio tape (DAT) and Telepoint portable telephone system. They are central to future innovations such as 4G/5G mobile communications, computer operating systems and Internet, and the integration of computers, media and telecommunications now underway. Once new technology is developed and embedded, standards continue to affect competition. A standardized design, unless kept exclusive, allows easier entry to the market, increases competition, makes product differentiation more challenging, and may reduce profit margins. On the other hand, the vast markets opened up by standards make related technological development more worthwhile and allow firms to specialize in components rather than building the whole system. Standards make modularization possible, and this in turn allows entry into the business by specialized firms. Standards not only affect manufacturers; they also concern producers of complementary goods and services and consumers, none of whom want to be left supporting an obsolete standard.

Standards add value by combining two main functions: allowing interoperability and incorporating innovation from multiple technology developers. Interoperability, or compatibility, allows products from different manufacturers to share components and operate together in networks. Compatibility adds value by increasing the size of the market for complementary products and services, such as components or computer printers, making them cheaper to produce and available in greater variety. Interoperability allows core products to be joined together in networks, such as mobile communications, with direct benefits of having more users to call and larger network infrastructures, as well as providing economies of scale in production and use. These network effects work via the demand side, making the core product more attractive the larger the installed base. They are often called "externalities" because each adoption benefits all users, not just the individual.

Standards also guide and incorporate innovation by coordinating development and selecting new proprietary and non-proprietary technologies, and anointing a dominant design. In dynamic industries such as ICT, where technology is moving rapidly, new technology, requiring hundreds of millions of dollars of R&D effort, is often developed anticipatorily before implementers make expensive downstream investments. Implementers need an agreed standard to avoid committing to a dead-end standard too soon. Similarly, technology developers want to avoid investing large amounts of R&D in technology that has no prospects of being adopted in a standard. They may not always succeed in doing so. For instance, many technology practitioners contributed to the WiMAX standard, but it failed in its main market. To condense the total time needed for standardization, and weed out unsuccessful technologies early, developers often promote their technology commercially before it is fully developed. Technology and standards are developed concurrently, at least as far as tailoring technology to the needs of the standard. Once a technological approach is adopted it has a good chance to become the dominant design for that generation of standards. However, as with WiMAX, there is no certainty of outcome. Notwithstanding, successful standards do save wasteful duplication of R&D and focus future development on a given technology path, as well as provide a stable standard for implementation.

The net effect of both these functions is to make both core and network products cheaper to produce and more convenient to use, increasing the value of products and market demand. The relative importance of interoperability and innovation depends on the technology and industry. For some standards compatibility may be most important; the technology may be already developed or relatively straightforward, and products benefit mostly from connectivity. For other standards technology may be moving forward rapidly but depends on interoperability to be effective. In such cases the coordination of interoperability and technological innovation in standardization is vital.

2.2 Factors in standardization

To understand standards development processes, we need to make a few preliminary distinctions. These help distinguish different types of standards and the standardization strategies that may be appropriate in a given environment.

Standardization process – A basic distinction is between standards set by market forces (*de facto*) and those mediated by standards bodies (*de jure*). Some standards set *de facto* by market competition may later be confirmed as formal standards for clarification and wider approval. Perhaps because of the awareness of their strategic importance, increasing numbers of standards are today created by some form of *de jure* committee, such as a standards development organization (SDO) or a consortium, rather than evolving without coordinated guidance. Many standards are set by a combination of market forces and committees, using standards organizations to define standards but mixing these with market forces to speed up the process and prove concepts in the marketplace. Committee standardization may outperform the market as coordinating mechanisms in some circumstances, being based on consensus and less likely to lead to standards contests, but can take longer and be less flexible. In some cases, hybrid systems have advantages, and in some situations may avoid the drawbacks of the other systems.[4]

Product scope – Standards may also differ in scope—how broadly the standards define the product features and whether they are key characteristics or peripheral to value of the product. The degree of standardization is the proportion of product characteristics covered by the standard and how important these are to product demand. Some standards may define most or all relevant features, with little chance of differentiation. Others may define the main interfaces, which benefit all producers, but allow products to differ in or compete on other features. For example, petrol octane ratings almost completely define the product and radically changed the focus of competition when they were introduced. Direct network standards such as telephones or railways also need a high degree of standardization, but questions remain of other value added by product features outside the standard itself. Technical standards may also operate at different design levels (i.e., the "depth" to which standards are integrated into the technical functionality of the products).

Market extent – Standards may apply to different product and firm groups. Multifirm standards are adopted by different firms producing similar products. Multiproduct standards apply across products from the same product area within the firms. Multi-vintage standards apply over different technical generations of a product. A typical issue for generational standards is whether, or how, to achieve backward compatibility with products that use earlier-generation standards, and vice versa.

Fragmentation – A standards-related market may fragment into distinct standards, each with its support groups. One extreme is the monolithic standard, a single standard for the whole industry. Alternatively, several different standards may share the market. To survive, each standard needs to have a critical mass large enough to compete in the long term against other standards. For example, personal computers (PCs) have supported two standards in stable equilibrium: Windows and Apple; mobile phones also focus on two main standards: Android and iPhone. VCR gravitated to a single Video Home

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[4] Farrell & Saloner 1988 compare extreme cases of standards set by committee negotiation and those set by firms that only "communicate" by making investments in the marketplace, without prior negotiation. They show that in theory a committee may be more likely to arrive at a common standard because negotiations take place before irreversible investments are made and there is less chance of choosing fragmented standards by "mistake." Committee standards may be set later than market standards, but the cost of delay is more than offset by the greater likelihood of agreement. In the hybrid system, the ability to make preemptive investments strengthens the ability of firms to make commitments in the negotiation process and so may be best of all.

System (VHS) standard. However, splitting the market between several small standards may mean that none gets the full value of standardization. One aim of cooperative standards development is to avoid fragmentation.

Standards control – A key strategic distinction is the control firms have over access to a standard, whether proprietary or open. With a proprietary standard, a firm or group of firms may have key intellectual property (IP) rights over features in the standard and use this to restrict adoption by other firms. With an open standard no restrictions are placed on other firms adopting the standard and imitation is usually encouraged. IP is made available for use in open standards, and IP rights are either waived or licensed for fees. The commitment that many standards organizations require from owners of standards essential patents (SEPs) to license these for use in open standards on fair, reasonable, and non-discriminatory (FRAND) terms, as a condition for including the technology, may formalize this. A second aspect is the leadership of the technological development of the standard—whether a firm develops or adopts. Even open standards are likely to be led by key developers who define the standard and lead further changes.

2.3 Standards organizations – SDOs, consortia, and SSOs

Various organizations are used to develop standards. Organizations that set standards via committee differ partly in the extent to which market forces are involved in standardization. Some standards may be set *de facto*—almost purely by market forces, as discussed above. In practice, major standards may be developed by combining some form of *de jure* standards organization with a degree of market activity to speed up standardization and innovation as well as form alliances and assess competition in market conditions.

One main distinction is between formal standards development organizations (SDOs) and informal industry consortia, alliances, and special interest groups (SIGs).[5] SDOs have specific structures and formal policies intended to coordinate the development and implementation of technology and standards, and to balance the interests of the developers and implementers. SDOs are usually accredited by national and global standards institutions and conform to their policies within the international structure. Standards are typically open, and IP policies to require disclosure of essential IP and the commitment to license this to any firm wishing to implement the standard on FRAND terms are common to almost all SDOs. SDOs also accredit testing for standards compliance and contribute to general standards policy development. Procedures are formalized, based on voluntary participation and consensus. Reports on process and the standards themselves are usually publicly available.

Private consortia and alliances develop standards outside the SDO structures. For fast-changing technologies, formal SDO processes may be too slow and time consuming, and consortia are increasingly used as faster, more flexible alternatives. Consortia can take various forms, from large organizations that match many of the functions of formal SDOs to small *ad hoc* working groups of firms set up to create a narrow standard or test a new field.[6] They may have any IP policy they like within the confines of competition and other laws. Standards may be open or proprietary. Procedures may take many forms and need not be reported publicly.

Advantages of SDO standards are that they are developed following well-known principles of openness and voluntary consensus. Standards may be relied on for broad support and global adoption. SDOs often

[5] Updegrove 2007; Cargill 2002.
[6] In practice, consortia are likely to have narrower membership than SDOs, which are open to all firms, developers, or implementers, as well as consumers and government representatives. Some consortia are governed mainly by developers; others may be geared toward the interests of implementers.

have broad memberships, including developers, implementers, service providers, customers, and regulators. However, SDO procedures take a long time and need to reconcile widely different interests. By comparison, consortia can operate flexibly without cumbersome structures and may be better suited for fast-moving new technologies. Conversely, they may have limited support and lack the credibility of formal SDOs. SDOs may be needed where investments are large scale, standards need to encompass the whole industry, and uniform compliance and coordinated development are of greatest importance. Consortia may be more effective where technology is as yet undefined, there are only narrow interests, and standards are more experimental.

In some cases, SDOs and consortia cooperate, using private consortia to develop many of the technical aspects of a standard, and if supported broadly enough, transferred to SDO processes for formal standardization. We see this in some of the case studies.

We also make a further terminological distinction between "standards development" and "standards setting." These apply to the scope of a particular standard rather than an institution. Some standards go deep into the technology design and are central to performance (e.g., the radio interface in mobile communications and the specification of CDMA versus TDMA wireless transmission). These standards combine technology development and interoperability strongly. They may have a major impact on operations and contribute directly to the value of the products as well as that due to compatibility effects—they are "fundamental" to product design. Other standards may be primarily concerned with interconnection and may not be especially critical to the choice of dominant technology (e.g., a pin layout for memory components or electrical plugs). These standards are likely to have some technology dimensions but may involve a choice between near alternatives and derive most of their value from compatibility—everyone doing the same thing. The first type of standardization we call standards development and the second standards setting. In some cases, they may take place within the same organization according to the standards.

Recent practice has been to refer to all standards organizations—whether SDO or consortium, standards developer or standards setter—as standards setting organization (SSOs). In some cases, however, this can be misleading, as all standards organizations are not alike. One of the main functions of standards development organizations is innovation, as well as interoperability, and calling them all standards setting organizations blurs and ignores this. The term SSO may imply incorrectly that standardization is just a question of selecting between candidates with no role in development of the underlying technology. The distinction between SDOs and SSOs is not just semantic, because it may affect how developers and implementers relate to each other. As used herein, the term SDO refers to formal standards organizations involved in developing standards and incorporating new technologies; the term SSO refers to organizations that set standards without a strong technology development dimension. Consortia distinguish private standards organizations, most likely for standards development, outside the formal SDO organizations. The general term is standards organization (SO).

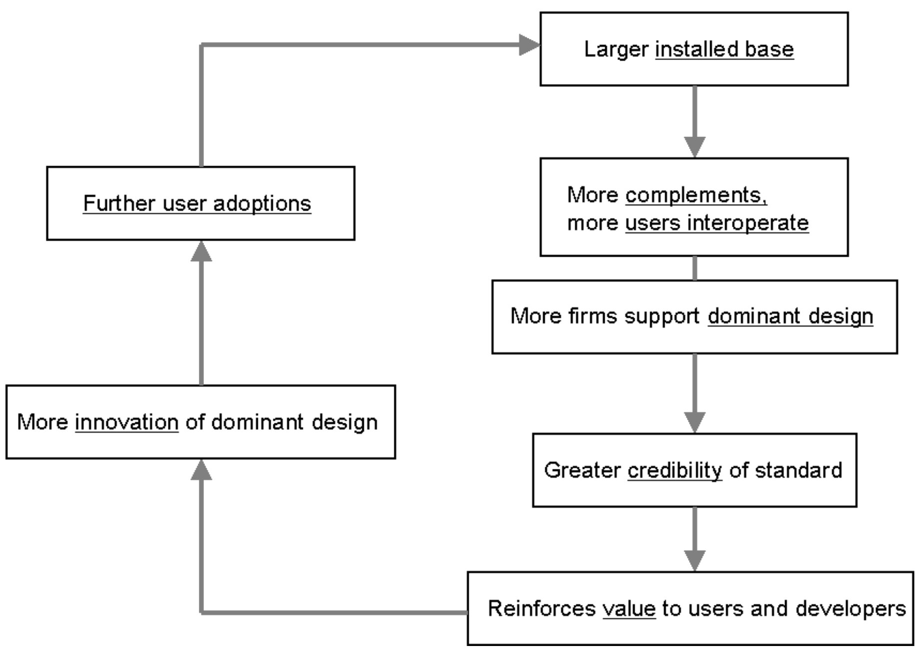
2.4 What makes one standard more successful than another?

a) Dynamics of standardization

A discussion of standards strategy must start with the dynamics of standardization. Standards markets do not act economically like many other types of products. Normal products may coexist in the market and compete with each other over the long term for market share. For standards products, the benefits of belonging to a leading standard are often so great that the entire market may tip toward a single standard, leaving others with no share. Strategy focuses on influencing this process in one standard's favor, often within a narrow time window as a new standard is being introduced.[7] A primary need even for standards products is first to develop a design that is acceptable to the market, but at some point as the product is introduced the standards effects take over. These can make or break a new product.

The basic mechanism depends on network effects, which make standards more valuable as the installed base of users grows. The larger the actual or expected installed base, the more attractive adoption of the standard is to new users and to implementers and innovators. This makes more complements available and increases the credibility of the standard. In a market situation, this leads to more adoptions as new consumers and innovators focus on the leading standard. This may lead to winner-take-all situations. An alternative if this process is interrupted, or several standards are able to establish themselves, is fragmented standards. Each of the standards may be too small to achieve the full economies of scale possible with a single standard, but their adopters may be unable to switch. Developers, implementers, and consumers want to avoid being locked in to poorly performing standard and go to lengths to avoid this.

Figure 1: Standards reinforcement mechanism



The standards reinforcement mechanism is illustrated in **Figure 1**. The larger the installed base of users, the larger the market—leading to more complementary products, more users to interoperate with, and more innovators and manufacturers supporting the design. A larger base with more development and implementation increases the credibility of the standard—important for expectations early in the standards adoption process. This attracts more new users and innovators, which further increases the size of the installed base. Growth accelerates for the standard, with the largest base and “bandwagon” effects taking over. In a contest, the leader may soon have such a large advantage that all new users choose it, “tipping” support toward the leading standard and sweeping the market. Only if other standards have managed to build a sufficient installed base of their own before this happens, or are very

[7] For further discussion of standards dynamics and strategies, see Gabel 1987; David & Greenstein 1990; Farrell & Saloner 1992; Besen & Farrell 1994; Grindley 1995 (Chs. 1–3); Wiki Books 2012.

strongly differentiated, can they maintain any presence.

When introducing a new standard, early adoption decisions depend critically on expectations of whether a standard is likely to succeed. Users want to avoid being stranded with a minority, unsupported standard, while manufacturers and developers want to choose the standard with the greatest market potential. If the product is new, expectations are based on whatever information is available. A small initial advantage may help set the cumulative support process in motion, making chance events as well as strategy important. To get the standardization process moving, firms may make initial investments in complements and subsidize early users. They may influence adopters by preannouncements and user education, but these need back up with proven features, evidence of commitment, manufacturing capability, and complementary support. Given uncertainties, an initial installed base may be the strongest indicator of the standard's chances. Credibility may be less important later, once the prospects for the standards have become clearer and the physical installed base effects tend to take over.

A result is a "window of opportunity" during which firms may influence the standard, from the time a new product has been developed to some basic level of user acceptability until some standard has built a dominant lead. Often, there is a period of rapid technical development of several competing products, until one or more have reached some level of market acceptability. The dynamics then take over, and once the bandwagon favors a particular standard, a "dominant design" emerges rapidly.

b) Establishing successful standards

Firms may influence these dynamics in a number of ways. The basic objective for a successful standard is to build its credibility and installed base of support during the introductory period, more quickly than competing standards. Some of the efforts may need to take place before standards are launched, others in the critical early stages. Firm strategies aim to ensure the success establishing a standard as a whole and to optimize their position and earnings within that standard. We discuss overall standards strategies first.

Steps are equivalent whether standards are developed via market forces or within a standards organization. For market-based standards, firms may be more likely to need private alliances to gather wide support and to organize private means to establish credibility and installed base. In industries dominated by formal organizational standards, the task for the firm may be more focused on establishing its position within the standard and influencing the standard as a whole, to help ensure that it prevails against competing standards. Otherwise most steps apply in either case.

A number of key enabling strategies may be used by sponsoring firms to attract other manufacturers and users to a standard and to establish a successful standard (see **Table 1**).

Table 1: Standards Enabling Factors

Type	Factor
Basic mechanism	Installed base and cumulative sales
	Credibility
	Technological design
Gaining support	Timing
	Sponsorship
	Alliances
	Official standards bodies
Competing with alternatives	Penetration pricing

Preannouncements
Linkage and indirect routes

Build the installed base – A main priority is to build the installed base and establish a “critical mass” of users quickly to start the network effects. It is important that the standard gets off to a good start and maintains momentum. Strategies include strong promotion, lining up manufacturing and distribution capacity and pricing aimed at adoption rather than immediate profits. An obvious way to bring in supporters is if the standard is open. Though this means accepting competition, it may be the only way to establish a standard if faced with a strong alternative. A key measure of progress is *cumulative* sales. Sales and even market share may be increasing, but if a competitor has an even larger share and its base is growing faster, it will eventually dominate the standard.

Establish credibility – Early purchasers and co-producers make their decisions based on expectations of the standard’s prospects before the installed base and complementary markets have built up. Expectations may be raised by advertising and promotion, educating the market, and fast publication of favorable market results. A problem is that new products have no track record, and firms with excellent reputations in an old technology have often failed in a new one. It depends on putting together a convincing package of suitable product, manufacturing capacity, financial backing, maintenance support, and the availability of complements.

Broaden the design – The winner of a standards contest is not necessarily the most technologically advanced but the one that will gain the broadest support. Technological performance is central to a standard. However, once the product is developed to a point of user acceptability it can become relatively less important. The aim may be a standard that “satisfices” rather than optimizes the design, after which other aspects of strategy take over. The standard should if possible be brought to this point before it is launched. A constantly shifting design confuses the market, and a reliable, stable standard may be more important than state-of-the-art design. Technology may still be a major element in a standards contest, for cost reduction and adding performance features outside the standard. There are also important opportunities to improve the basic standard once it is established. Generations of standards improvements are a common feature in ICT.

Timing is everything – Timing is critical; strategy depends on not just the actions but also when they happen and how long they take. Skill comes in recognizing the “window of opportunity” between being premature, launching the standard before it is acceptable by the market, and being overdue, once some other standard is too strong to change. This involves flexibility as well as speed. A useful ability is being able to realize when it is too late for the firm’s standard to win the contest and it is time to accept another firm’s standards regime.

Sponsor co-producers and initial users – To get over the coordination hurdle of ensuring complements for the initial users, the manufacturer may need to sponsor early co-production. It may do this by providing information, education and training, and other incentives, or form partnerships with co-producers.

Form alliances – Establishing a support base for a standard almost always needs alliances between developers, manufacturers, distributors, and service producers. These help spread development and other costs, and ensure adequate manufacturing capacity and distribution. They may also help avoid fragmented standards. The broadest coalitions are those for open standards, sometimes against a proprietary threat that firms could not oppose individually. Alliances also add to the credibility of the standard and may reassure users investing in complementary goods and training.

Standards organizations – Firms may try to avoid expensive standards wars by using standards organizations to develop and agree standards. This is a major strategic decision for the firm, reflecting its choice of an open or proprietary strategy and other considerations, discussed below. The type of organization is also important. There may a tradeoff between the speed of development and flexibility available in the market or private consortium versus the breadth of support and reputation of formal SDOs. Which to use depends on the industry and the technology.

Price for market penetration – Conventional products are often introduced at high prices to recover R&D; prices are gradually reduced over time as costs fall. A first priority is to build an installed base quickly. Low "penetration pricing" may increase initial volumes and market shares. If the standard is successful, the investment should eventually be paid back handsomely. This may require high upfront investment, at a time when firms might otherwise rely on introduction prices to recover R&D costs and fund further development.

Use preannouncements – Product preannouncements are a particular way of influencing expectations. Since standards are often anticipatory, users may have little to go on and need education and demonstrations of the product. But preannouncements must be used with care. Announcing products that never appear is not a good way to establish credibility.

Use indirect routes – The initial installed base may be increased indirectly by making the new product compatible with an existing standard. This is an advantage for multigenerational standards. Adapters or translators may be needed for compatibility with an existing base. Even so, there is a limit to evolutionary standards. Adapters may be expensive, and standards may become locked in to an obsolete design. Eventually a radical break is needed.

The success of a standard and the strategies firms use depend on combinations of these strategies and the environmental factors affecting the industry, market, and technologies. Each situation is likely to be different. The most effective strategies may be those that can adapt flexibly and rapidly as the market develops. The basic economic mechanisms of standardization may be understood, but the applications always seem to provide new perspectives. As usual, the devil is in the details.

c) Firm positioning and profitability – open or proprietary?

The most basic strategy choice for a developer is between an open and proprietary standard. If the standards products have strong customer appeal, can be produced in quality, have a head start, and have strong IP, a firm may be able to establish a proprietary standard under its control. Without competitors, and with its customers locked in by network effects, a proprietary standard can be very profitable. This has worked for Apple in computers and mobile phones, for example, in some market segments.

In many other cases, the main sponsor of the standard may not have sufficient resources to develop the market on its own, and any attempt to do so would face stiff competition from other firms and standards. If so the firm may do better to open the standard to other firms, so as to build the installed base quickly, add to the credibility of the standard, and ensure that it will be supplied with plenty of complementary goods and services. The additional competition means that prices and margins for an open standard may be lower than for a proprietary standard, but the market is likely to grow more quickly and be larger overall. The firm may have a smaller share but of a larger market. A task for an open standard sponsor is to keep as large a share of the market as possible and not let its first-mover advantage be lost as other firms adopt and imitate the technology.

Implementers, complementary producers, and users face similar choices as to which standard has the best chance of success and will offer them the best returns. The basic positioning decisions determine each firm's contribution to the standard and the control it is likely to have over the standard.

Two key decisions for all firms are:

(a) *Leadership* — whether the firm develops its own standard or adopts from outside

(b) *Access* — whether the standard it supports is open or proprietary

Four options combining these strategies are shown in **Figure 2** and described in **Table 2**.

Figure 2: Strategic positioning

Positioning	Access: Proprietary	Access: Open
Lead (Develop)	Exclusive standard	Sponsor, Contribute IP
Follow (Adopt)	License In	Clone

Table 2: Standards positioning strategies

Exclusive standard	Develop a proprietary standard and restrict its use by competitors, charging significant license fees
Sponsor open standard	Encourage competitors to use an open standard incorporating technology contributed by the firm, contribute IP with moderate or no license fees (FRAND)
License in	Adopt a proprietary standard controlled by another (competing) firm
Clone / Adopt	Adopt an open standard, without restrictions

The leadership decision depends on whether the firm is able to develop a feasible design (or part of a design) compared to competitors, and on the intellectual property rights the firm holds. The access decision depends mostly on the prospects for establishing the standard as open or proprietary—an open standard is likely to have advantages of broader manufacturing and customer support compared to product advantages a proprietary standard may have. The basic tradeoff is that an open standard may lead to a larger total market, but the firm must share this with more competitors. Unit profits may be higher with proprietary control and the firm need not share the market, but an open standard market is likely to be much larger. Open standards may also shift the balance of power in favor of implementers and users, which avoids being dependent on a single supplier, further lowering the prices of core products and complements. Together these determine how competition for the standard is organized.

Many individual factors contribute to the positioning decisions. In positioning itself, each firm must balance the chances of the standard being adopted against its likely returns in each case. Tradeoffs in making these decisions among the likelihood of adoption, market size, market share, profit margins, and development costs are shown in **Figure 3**. The positive benefits of choosing to lead the development of a proprietary standard are high market share and high unit margins. Negative considerations include the low likelihood of winning a standards contest without outside supporters and the cost of sponsoring complementary production and initial users. For a leader of an open standard, the positive effects are greater likelihood of acceptance and larger total market, countered by the negative considerations of increased competition, low market share, and probably low margins.

Figure 3: Strategic positioning — costs and benefits

	Proprietary	Open
Lead	+ Protected market + High margins + High share + High license earnings - Low chance of winning - Limited external support - High cost - Small niche likely	+ High chance of winning + Large market + Broad external support + Shared costs - Low share - Low margins - High competition - Modest license earnings
Follow	+ Proven market + Possible alliance - Secondary position - High license fees - Emulation lag - Transfer costs (adaptation)	+ Best chance of winning + Equalized competition + Modest license fees - High competition - Undifferentiated product - Transfer costs (adaptation)

IP is an important factor. Depending on its business model, if a firm's IP is strong the sponsor may claim an appropriate share of others' profits via licensing. It may be able to differentiate its own products in some way with other features or technology, as worth a premium, or aim to lead further development of the technology to keep ahead.

To attract other adopters, the innovator must also give credible assurances that it will continue to make the standards essential technology available, including future enhancements; otherwise other implementers and customers will fear that the sponsor will try to take back control of the market once the standard is established. This need to keep the standard open is part of the logic behind the FRAND commitment. The IP holders guarantee that they will make IP available to anyone practicing the standard, and at FRAND rates.

Other strategies may be used around the open standard. A developer may specialize in the core product and leave others to provide complements. Strangely, an alternative may be to become more vertically or horizontally integrated, if this produces a more consistent high-quality product. Or a developer might choose to focus on technology development only and earn its return via licensing.

Firms that lose a standards contest or were never involved in the contest face choices, too, of which standard to support. Their thinking is similar to the leader, of which standard has the best chance of being established in the market and what steps the firm may take to profit using the standard it had adopted. This might include product differentiation, superior manufacturing and marketing, or contributing to the further development of the standard.

Firms should also remember that standardization is not a single game. It will be repeated, and there may be a chance to improve one's position over time. Once a standard is established, firms compete for share within the standard and may develop further enhancements. Most standards are improved immensely during their lifetime with regular updates, additions, and replacements. Intergenerational competition gives firms an opportunity to enter the market or increase their share by leading the development of the next standard.

The sizes of the costs and benefits for the firm depend on the industry and the standard. The more advanced the development of a competing standard and the stronger the manufacturing, marketing, and financial capabilities of competitors, the lower the chances of a proprietary standard winning a contest. A proprietary strategy also requires strong IP to protect the standard from unwanted imitation. Similarly, the threat of a strong proprietary standard increases the attractiveness of an open standard to the weaker players and raises its chances of recruiting enough support to win the contest. The selection factors include the likely effectiveness of the enabling strategies.

3. Case Study 1: Electrical connector standards

3.1 Introduction

Many aspects of modern products depend on electrical connectors. Devices need power, and many need to communicate with other devices and send and receive signals. Computers and peripherals are connected to signal sources and interoperate in networks. The main value of connector standards is likely to come from compatibility. The design of the connectors themselves may not be critical to the value of the final product, but the fact that plugs and connectors from any manufacturer can interconnect to power supplies and each other is fundamental.

To take a basic example, electrical plugs are usually standardized on a national basis so that appliances can connect to the power supply. The design of the plug is not critical; many designs might be adequate. Indeed, although they all have the same function, plugs from different countries have slightly different shapes, and adapters are needed when travelling internationally. What matters most is that they are compatible, at least nationally.[8]

This is not a complete separation between compatibility and technology, as even here the connectors are not isolated from the rest of the system. Domestic electrical power wiring in the UK mostly uses a ring circuit, which has a central circuit breaker, but each plug contains a separate fuse.[9] Other countries (and lighting circuits in the UK) use a radial circuit with fuses kept centrally, not in the plug.[10] Plugs also have to contend with different supply voltages—110 to 120 volts in the US, 220 to 240 volts in most other countries—and are designed accordingly.

Computer connectors show many of the same distinctions. Although the design of the different styles of connectors is not trivial, it may not be a major contributor to product value. The main purpose is efficient interconnection, and a main effort is to coordinate the adoption of a given design for different products. This again is not quite so simple. Designs may be developed privately for specific applications with different performance aims and may be incompatible with each other. Designs may be proprietary or open. They may also have different implications for the rest of the system. Some computer connectors, including those discussed below, require devices to share interface management, on a peer-to-peer basis. Others manage the interface within the host computer and must be able to operate with a wide variety of connected devices.

This section looks at the standards development of two of the most widely used computer connectors.

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[8] The wide variety of territorially incompatible electrical plugs and electrical outlets around the world illustrates potential problems caused by a lack of international standardization. This may or not be a major hindrance to trade or travel depending on how inconvenient it is to convert between types.

[9] Latimer, D.W.M. 2007.

[10] With radial circuits, the cable comes from the consumer unit and travels to each socket, similar to the ring circuit. However, when the circuit reaches the last socket, the cable ends, whereas a ring main travels back to the consumer unit. https://www.diynot.com/pages/el/el011.php

FireWire serial bus was originally developed by Apple and also transferred to the Institute of Electrical and Electronics Engineers (IEEE) for development as a formal open standard. Universal Serial Bus (USB) was developed by a group of electronics companies as a cooperative standard and maintained as an open standard by an alliance, the USB Implementers Forum (USB-IF), set up by them. FireWire was designed originally to fit Apple's needs but has been adopted by other firms. USB was developed as a collaborative venture to replace and unify a plethora of earlier parallel and serial port connectors and is widely used. Both standards have been further developed over time, especially USB, which has had a number of generations with improved performance. FireWire is now little used; USB has taken the main connector role, and Apple has shifted to a new connector that has been developed, Thunderbolt.

These standards show different processes for developing and commercializing standards, both proprietary and open. They also illustrate combinations of private and public standards development. Technologies and standards developed in private firms may be submitted to SDOs for formal standardization or developed in consortia acting in many ways similarly to SDOs.

They may also give some insights into the relative importance of innovation and interoperability. Connectors may not be very significant to some products, such as electrical appliances, so long as they can connect to a power source—other independent features of the products are more important. Product features may be left to market competition to develop and the connectivity standards (e.g., plug standards) agreed as needed.

Interconnection may be more important to other products, such as mobile phones or movie cameras, which depend more centrally on interoperability: a high-quality connector may be a big advantage for the product. In that case, connector standards are vital and likely to be developed in parallel with the technology. This may include formal cooperation between firms, as well as the use of market forces. For electrical appliances, connectivity standards may be established as a convenience for the market as a whole, but for mobile communications interoperability must be built in to the product from the beginning. We see some of these issues in electrical connector standards.

3.2 FireWire

Apple began development of FireWire around 1986. It was intended as a serial replacement for the parallel SCSI bus, while also providing connectivity for digital audio and video equipment. It was intended as a relatively inexpensive, high-speed connection that was easy to use, but Apple did not originally intend the technology to be used as a connection for external (non-Apple) devices.[11]

FireWire was used by Apple in some of its own products and by other companies such as Sony for some years, but was also brought to IEEE for formal standardization.[12] This standard development was driven mainly by contributions from Apple, although efforts were also made by engineers from Texas Instruments, Sony, Digital Equipment Corporation, IBM, and INMOS/SGS Thomson. The standard was ratified in January 1995 as the IEEE 1394 High Speed Serial Bus. Since then, there have been a number of enhancements to IEEE 1394 standards, the latest being IEEE 1394-2008.

FireWire was popular for audio and video devices like digital camcorders mainly because of its high speeds, with a data transfer rate of up to 400 Mbits/s on the original FireWire 400 standard, compared to the first version of the USB standard in 1998 of only 12 Mbits/s. This had clear advantages when transferring large files. Speed continued to favor FireWire for over a decade. When USB 2.0 arrived in 2000 with a 480 Mbits/s transfer rate, FireWire responded with the FireWire 800 with an 800 Mbits/s transfer rate. When USB 3.0 arrived in 2008 with speeds of up to 5 Gbits/s FireWire could not match

[11] Smith 2011.
[12] IEEE 1394 interface has been marketed by Sony as i.Link and by Texas Instruments as Lynx.

this; it became less attractive and was eventually superseded for most uses.

Most Apple Macintosh computers between 2000 and 2011 included FireWire ports. Apple introduced the first commercially available computer with Thunderbolt in February 2011 and stopped using FireWire in its computers in late 2012. Thunderbolt has effectively become the successor to FireWire in the Apple ecosystem. Apple also uses its version of USB 3.0 called USB 3.1 type C.[13]

Thunderbolt was mainly developed by Intel. It was initially named Light Peak and first sold in 2011. Light Peak was at first intended to run on optical cabling. However, it was discovered that conventional copper wiring could support the desired 10 Gbits/s per channel speed at lower cost. This copper-based version of the Light Peak concept was co-developed by Apple and Intel. Apple registered Thunderbolt as a trademark, but later transferred the mark to Intel.[14] Thunderbolt 1 and 2 use the same connector as Mini DisplayPort (MDP), whereas Thunderbolt 3 uses USB Type-C.

3.3 Universal Serial Bus (USB)

The USB is a family of standards that was developed originally in 1996 by a group of seven companies: Compaq, DEC, IBM, Intel, Microsoft, NEC, and Nortel. It aimed to replace the many legacy ports on a computer, including serial ports, parallel ports, PS/2, game ports, and others. These all used different plugs and needed to be configured separately. USB makes the addition of peripheral devices quick and easy for an end user using a single standardized interface. Peripheral devices such as keyboards, mice, printers, scanners, mass storage devices, telephones, modems, digital cameras, video cameras, and audio devices can be plugged into a computer USB port and have them automatically configured and ready to use. USB has become the *de facto* industry standard for connecting peripheral devices to PCs and laptops.[15]

USB has been substantially improved and enhanced since it was first developed. In terms of data transfer rates, USB Version 1.0 (June 1996) had a maximum speed of 12 Mbits/s. Version 2.0 from (April 2000) had a maximum speed of 480 Mbits/s. Version 3.0 (November 2008) had a maximum speed of 5 Gbits/s. The latest Version USB 3.1 (July 2013) has a maximum speed of 10 Gbits/s.

There are a number of different form variants. There are three basic formats of USB connectors: the default or standard format intended for desktop or portable equipment (e.g., USB flash drives), the mini intended for mobile equipment (little used now, other than the Mini-B, used on many cameras), and the thinner micro size, for low-profile mobile equipment (most mobile phones).[16] It currently comes in ten different form factors (type A, type A SuperSpeed, type B, type B SuperSpeed, Mini-A, Mini-B, Micro-A, Micro-B, type C, and Micro B SuperSpeed) in a wide range of sizes. The number of pins ranges from 4 to 24.

The USB Implementers Forum (USB-IF) was formed in 1995 by the group of companies that developed USB, as a nonprofit organization to promote and support USB. Its main activities are the promotion and marketing of USB, Wireless USB, and USB On-The-Go, and the maintenance of the standards specifications as well as a compliance program.[17]

3.4 Comparing FireWire and USB standards

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[13] Wuerthele 2016.
[14] Shah 2011; Oliver 2012; 9to5 2011.
[15] http://www.usblyzer.com/brief-usb-overview-and-history.htm ; https://www.techopedia.com/definition/2320/universal-serial-bus-usb
[16] Ngo 2016.
[17] http://www.usb.org/about

a) Technical differences between FireWire and USB

There are several technical differences between FireWire and USB that show that connection standards are not simply a question of the external shape of the plug but may define significantly different alternative approaches to the design of the interface system as a whole.

One important distinction is that FireWire and USB use different systems architectures. This initially favored FireWire, but with constant improvements USB eventually matched and exceeded its performance. FireWire uses a "peer-to-peer" type of architecture where each device controls itself, ultimately reducing the load on the main computer. This allowed FireWire to have higher sustained transfer speeds compared to USB 2.0. Standard USB uses a master-slave architecture where the main controller (computer) is responsible for data flow and other functions.[18] A host acts as the master device for the entire bus, and a USB device acts as a slave. Devices must assume one role or the other, with computers generally set up as hosts.

Because FireWire uses a "peer-to-peer" architecture, the ends of standard FireWire cables are the same, because unlike USB there is not a master or a slave. This allows the user to connect a range of devices together; for example, Camcorder - External Hard Drive, Camcorder - Computer, Camcorder - Camcorder. By contrast, USB has different-shaped plugs for the peripheral and the computer so that they do not get reversed.

b) Comparative standards development processes

For FireWire, Apple developed the technology and standard privately, and then brought it to IEEE 1394 working group to be developed as a formal open IEEE standard. The benefits of becoming an SDO standard presumably include an increase in the credibility of the standard and the commitment to make it available to all comers, and the consensus process that ensures that it meets the requirements of a wide range of potential users. The use of a patent pool makes the license terms transparent.

By contrast, USB has always been developed by a private alliance of firms sharing a common interest in a single connector to replace the then existing plethora of different computer connectors. Having broad support, it was not necessary to bring the standard to an SDO for formal standardization. It is now maintained and improved under the auspices of the USB-IF, a private user group supported by the original developers.

c) Differences in adoption, rollout, royalties

FireWire has been relatively successful in not only Apple products but also those of other manufacturers, notably in camcorders. It was the most effective high-speed computer connector of its type between about 1996 and 2008. After 2008, USB 3.0 matched FireWire speeds, and FireWire fell out of use.

When USB was introduced in 1996, it was low speed and did not at first attract much industry interest. It also had to overcome the installed base of existing connectors and manufacturers unwilling to commit to the new USB unilaterally. It is claimed that USB didn't get wide industry support for years until Steve Jobs revealed the original iMac with USB 1.1, in 1998.[19] This only had one type of interface, USB, and

[18] http://guides.macrumors.com/Firewire; http://www.computer-solutions.co.uk/info/Embedded_tutorials/usb_tutorial.htm

[19] Wuerthele 2016. “The iMac’s sole reliance on the USB interface meant that Mac users had to throw out all their old mice, keyboards, scanners, printers, and external drives. …, the iMac provided the first kick start USB needed to really get off the ground. Thanks to the iMac, many peripheral manufacturers launched their first-ever round of USB computer accessories.” Edwards 2008.

provided the base for manufacturers to start offering USB products. As USB performance and capabilities improved, it established itself as the leading computer connector and is now found in almost all personal computers and other electronic products.

As an open formal SDO standard, Firewire IEEE-1394 is available to all implementers as an open formal standard licensed on FRAND terms. Companies holding IEEE 1394 patents out-license these via a patent pool administered by MPEG LA to whom they licensed patents. MPEG LA sublicenses these patents to providers of equipment implementing IEEE 1394. Under the typical patent pool license, a royalty of US$0.25 per unit is payable by the manufacturer per finished product.[20]

The USB standard is royalty free, but manufacturers need a Vendor ID and Product ID from the USB Implementers Forum in order to be certified as USB-compliant and use the USB logos. The Forum currently charges non-member manufacturers a biannual fee of $3,500 for the right to use the USB trademark. The membership fee is currently $4,000 per year. Although these sums are modest for a large company, there have been questions whether they might penalize small startups. The Forum rejected suggestions that the system be changed to open source in October 2013. [21]

4. Case Study 2: Video Recoding – VHS vs. Betamax

4.1 Introduction

The contest between VHS and Betamax video cassette recorder (VCR) formats in the late 1970s is one of the most famous standards competitions. Together with the introduction of the personal computer (PC) in the 1980s, it is probably the battle most responsible for bringing standards to general attention. This perhaps set a background to the major litigations from the 2000s onwards that have punctuated the licensing of standards essential IP in mobile phones and computing. Sony's Betamax was introduced in 1975 and JVC's VHS in 1976. Though similar in design, tapes from one format could not be played on the other's machine. Despite its later start, VHS outstripped Betamax and eventually drove it from the market. VHS's success was clear as early as 1978 as its sales increased, yet it was another nine years before Sony admitted defeat and began producing VHS format in 1987, although it continued to produce some Betamax machines for niche markets. Producers of the only other system launched, V2000 in Europe, had already adopted VHS. That only a single standard prevailed, rather than dividing the market between standards, shows the power of standardization, which can eventually overshadow other product differences.

This section summarizes the history of VCR development and the standards contest between VHS and Betamax. It reviews the standards strategies of the two firms and the relationship between these, the technological development of the two formats, and the expansion of the market. These three aspects worked together to ensure the success of VCR and in particular of the VHS standard. Both JVC and Sony, and others, had developed attractive new products, but the combination of steps followed by JVC for VHS was most effective. Although technical differences between the formats were relatively slight, they were enough to make VHS more attractive as a consumer product and enabled it to enlist other manufacturers and to be more successful in the marketplace. VHS overcame Betamax's early market lead, and once network effects began working strongly in its favor it took virtually the whole market. Partly because of JVC's open standard strategy, VCR, as VHS, became one of the most successful consumer electronics products of all time and led to substantial profits for JVC and to others in the industry.

[20] http://www.mpegla.com/main/programs/1394/Pages/FAQ.aspx
[21] Smith 2013.

4.2 History of VCR

a) Development of VHS and Betamax

The key dates in the history of VCRs are summarized in **Table 3**.[22] The main development phases of consumer VCRs occurred between about 1970, when JVC and Sony began work on adapting professional recorder technology, and 1976, when JVC launched VHS. There was a short-lived technology-sharing agreement between Sony, Matsushita, and JVC in 1970, aimed to perfect the cassette mechanism ultimately used in the Sony U-matic. This gave some commonality to the basic technology. Because of competitive pressures, the firms returned to independent development after 1971.[23] Betamax launched in Japan in 1975, while VHS launched in 1976. From the start, VHS was licensed to several of the largest Japanese manufacturers. In response, Sony attempted to catch up and made some less-extensive manufacturing arrangements in 1977.

[22] For VCR history, see Granstrand 1984; Total Rewind 1990; Cusumano et al. 1992; Grindley 1995 (Ch. 4); Moulding 1996; Maybury 1997; Sony 1996; Wielage & Woodcock 2003; Milestones 2006; Panasonic 2014.
[23] Granstrand 1984; Cusumano et al. 1992; Wielage & Woodcock 2003.

Table 3: Timetable of Main Events for VCR

Date	Event
1956	First audiovisual tape (AVT) — Ampex
1970	First prototype of consumer VCR
1971	JVC begins development work on home video recording system
1972	VHS Development Matrix sets out main features and specifications
1973	First VHS prototypes built in secret
1974	Betamax prototype — Sony (1 hour)
	Sony proposes that Matsushita, JVC adopt Betamax
1975	Betamax launch in Japan and USA (1 hour)
1976	Hitachi, Sharp, Mitsubishi adopt VHS
	MITI proposes JVC adopt Betamax
	VHS launch in Japan (2 hour)
1977	Matsushita adopts VHS, drops VX-2000
	Sanyo, Toshiba, Zenith adopt Betamax
	VHS launch in US
	Sony recorder launched — Japan and USA (2 hour)
1978	European launch for VHS and Betamax
	J2T agreement - JVC, Thorn, Telefunken, also Thomson
1979	Pre-recorded software reported important — 1000 Betamax titles
	Philips launches V2000 in Europe
1983	Philips starts production of VHS
1985	Miniature camcorders introduced — 8mm, VHS-C
1988	Sony starts production of VHS
1989	Sony introduces palm-sized camcorder

Sony had adapted the U-matic design to a consumer device and was ready to launch the product in 1975. JVC had at first followed suit, but then decided to start from scratch, with the first step its "VHS Development Matrix" in 1972, which set out twelve fundamental objectives for a new consumer VCR. The development of VHS was based on these aims. Critical features planned from the beginning included a two-hour recording time, affordable cost, and high-volume production.[24] These became the basis for JVC's subsequent strategy.

Chance also played a part. JVC almost dropped out of VCR in 1972 due to cost problems, but a team continued development in secret, and JVC eventually supported VHS officially when a prototype was developed in 1973. During 1974, JVC was shown a prototype Betamax recorder, and Sony repeated its offer to JVC to join with them and develop Betamax. JVC realized that Betamax was larger than its own prototype and could only record for one hour, half as long as VHS. JVC now had even more confidence in its system and decided to continue alone.

Sony launched Betamax in the US in April 1975. Aware of VHS, Sony prevailed on the Japanese Ministry

[24] Key performance features JVC believed were needed included compatibility with any TV, broadcast picture quality, at least a two-hour recording capacity, interchangeable tapes between machines, and versatility (e.g., able to tape from TV, play pre-recorded tapes, and read from video cameras). Consumer and manufacturing requirements were that players should be affordable, easy to operate, and have low maintenance costs. They should be capable of being produced in high volumes, parts must be interchangeable, and decks must be easy to service. JVC also recognized that the VCR would have an important role in the "information society." Maybury 1997; Knight 2015.

of International Trade and Industry (MITI) to ask JVC in 1976 to abandon VHS and join with Sony rather than risk a damaging format war. Unfortunately for Sony, JVC was by this time backed by Matsushita and also persuaded Hitachi, Mitsubishi, and Sharp to back VHS. Although Sony had by now launched Betamax in Japan, the support for VHS eventually led MITI to drop its push for a single Japanese standard and let the market decide.

JVC followed with VHS in October 1976. JVC had arranged US distribution of VHS machines by RCA, to be manufactured by Matsushita in Japan. Although Sony had licensed Zenith to distribute Betamax in the US, this was no substitute for RCA's huge distribution network. VHS overtook Betamax in its second year. By 1981, it already had 80 percent of the US market. Both products were introduced to Europe in 1978, this time with VHS ahead of Betamax. The original supporters of Betamax and the Philips V2000 soon switched to VHS. Sony eventually began producing to VHS standard as well as Betamax in 1988.[25]

b) Technical comparisons

Both VCR formats were developed from similar technology, based on cross-licensed research and development by Sony, Matsushita, and JVC in 1970. They relied on a "helical scan" system in which the recording track was written across the tape by a rotating magnetic head. The two systems were nevertheless incompatible—tapes from one could not be read by the other. The most obvious difference is that VHS cassettes were larger than Betamax, with a longer tape. After launch and as the market developed, there were a series of incremental technical innovations, which improved the basic design to a point where it became a major consumer product. Competition centered on a sequence of improved features, in which each firm tried to match or leapfrog the other.[26]

A sequence of product improvements focused on several feature areas, notably playing time, programming, and other features such as freeze-frame, slow/fast motion, scanning, and hi-fi sound. For example, playback time for Betamax was initially one hour in 1975, but was increased to two hours by 1977. VHS was introduced in 1976 with two-hour playback, but by 1977 had already introduced a model with four-hour playback. VHS introduced 24-hour programming in 1977 and seven-day programming in 1978. It was 1979 before programming was introduced for Betamax.

For each of the product features, competition continued until further improvement made little difference to the product. Competition then moved to another feature. For example, the most critical feature initially was playing time. The consumer breakthrough came when JVC introduced VHS with a playing time on a single tape of two hours—long enough for a feature film. Further extension to four hours gave some added advantage, but any further improvements (e.g., to eight hours) made little difference to the user. The feature had become "saturated." VHS systems were then introduced with automatic timers and sophisticated pre-programming. Once pre-programming could be set for a week in advance, with several different recording periods, there was no advantage in extending this facility any further.

In the early stages, JVC led Sony in features critical to consumer acceptance: playing time, size, and pre-programming. It was also preferred on the other aspects: price, ease of manufacture, and ease of servicing. Manufacturing simplicity made it easier to out-license, which increased the supply and variety of VHS products offered. Cheaper manufacturing also helped bring down prices, further enlarging the market. In the crucial stages, Betamax had only one product advantage: its slightly higher picture quality. However, this proved to be not significant enough to be noticed by most consumers, for whom VHS was adequate.

[25] Maybury 1997; Bylund 2010.
[26] Cusumano et al. 1992; Grindley 1995 (Ch. 4); Maybury 1997; Wielage & Woodcock 2003.

Eventually, Sony matched all the VHS features and began to lead the development in some areas. It was the first to introduce high-speed scanning, hi-fi sound, and 1/2 and 1/3 speed (extra-long recording). It introduced a high-definition version, Betaplus, in 1983. Sony ended up with a technically "better" product in terms of image quality and features. Unfortunately, this was too late to overcome VHS's entrenched position as the industry standard. JVC in turn matched Sony's innovations, and made some advances of its own. It introduced compact VHS-C for video cameras in 1982. In 1987, when it added Super-VHS, with high image quality capable of handling high-definition television and equal to laser disc and Betaplus, Betamax's last hope for VCR was gone.

4.3 The video recording format contest

a) Product and standardization strategies

To understand the VHS versus Betamax standards contest, we need to start with the development of the formats in the mid-1970s. Both formats were accepted as standards in 1976 by MITI, which contrary to its normal policy left the market to decide which format should prevail. This led to the battle between VHS and Betamax to become the dominant standard in VCR. The case illustrates many of the standards strategies outlined above in Section 2.

A central reason for VHS's success is that JVC followed a more effective open standard strategy for aligning other manufacturers and movie producers. JVC was more successful than Sony in finding partners. It did so by providing a system that, although second on the market, was more acceptable to consumers: this convinced a major section of Japanese manufacturers that VHS could command a wide market, which in turn helped its customer credibility when the product was launched.

When Betamax was introduced in 1975, it was manufactured only by Sony. Sanyo and Toshiba adopted Betamax in 1977. When VHS was introduced in late 1976, it was manufactured by JVC but soon joined by Hitachi, Sharp, and Mitsubishi—first marketing JVC machines and then manufacturing their own in late 1977. Matsushita, the majority stockholder in JVC, publicly adopted VHS in January 1977 and began manufacture.[27] Sony introduced Betamax in the US in February 1976, and JVC followed with VHS in January 1977. The key to US success was distribution. A turning point for VHS was its adoption by RCA in mid-1977. RCA marketed VHS machines, manufactured in Japan by Matsushita but sold with an RCA badge. Sony had set up a less-effective marketing agreement with Zenith in March 1977.

JVC had planned for this in a comprehensive approach combining technology, product design, and standards support. VHS was designed for market appeal rather than technological perfection, and was aimed at ease of manufacture. It out-licensed its format, as initially it did not have sufficient manufacturing capacity to cover the expected market. Although well known in audio, JVC was a relatively small company, unknown in television, and knew that it would have to rely on outside manufacture and distribution. The simpler construction made it easier for the manufacturers to adopt, while its lower cost increased its potential market penetration. JVC made VHS standards available to other manufacturers on liberal terms with minimal restrictions.

Its role as "underdog" may have been an advantage—it approached manufacturers as partners, not expecting unreasonable margins and not threatening the other firms' positions. JVC did not aim at market domination. It aimed at broad acceptance of the standard rather than trying to earn high initial rents. The returns would come over a long period once VHS was established. VHS also kept entry prices low, aimed at market penetration. Especially in the US, price competition was very strong, and VHS undercut Betamax from the beginning.

[27] Matsushita Electric Industrial Co. changed its name to Panasonic Corporation in 2008.

Sony, a larger company, initially followed a proprietary strategy and only reluctantly licensed other manufacturers in response to VHS. It had led the early development effort and was the first to market a moderately priced VCR. It felt it could establish Betamax as the leader, and then bring in other manufacturers on its own terms. Sony offered joint manufacturing and marketing but not collaborative development. Unfortunately for Sony, although it was first, its product was not quite ready for the mass market. Its one-hour recording time was too short, and the machine was bulky. It persisted in going ahead alone, investing in manufacturing and committing itself in the marketplace. By moving too early, Sony was tied to an inferior system, taking all considerations into account.

b) Pre-recorded movies

Complementary products, in the form of pre-recorded movies, became an issue in their own right for the first time as early as 1978. Initially, VCRs were mainly purchased for time-shift viewing and a certain amount of movies. By 1978, the installed bases were large enough to be worth producing pre-recorded feature films, as well as the use of video clubs and private borrowing to share the tapes. This was aided by a US Supreme Court decision in 1984 that allowed the use of VCRs for "time shift" viewing as fair use and not liable for copyright infringement. Pre-recorded tapes were available in either format, but as VHS's installed base grew this began to attract a greater range of movies. Later, Betamax was restricted to "blockbuster" movies. Once pre-recorded tapes began to appear primarily in VHS format, sales of Betamax fell precipitately.

Although the availability of complementary products such as movies makes a leading format more attractive, this does not seem to have been clearly effective here as a means of competition. Movie supply seems to have reacted to the installed base and consequent demand, rather than having been used actively to promote one format to the exclusion of the other. Since VCRs could do many things, their usefulness did not depend solely on pre-recorded software. Also, given the ease with which titles could be pirated, pre-recorded content was a difficult market to control. Thus the tendency was for software to follow the hardware base, confirming the leader rather than being a critical tool against a competitor.

c) Legal challenge

One challenge to time shifting was raised in the *Betamax* case, in which two major movie studios, Universal and Walt Disney, sued Sony, contending that the common consumer practice of using VCRs to tape broadcast TV shows and movies for later viewing was copyright infringement and that the VCR manufacturers were liable for contributory copyright infringement or inducement to infringe by providing the VCR devices that enabled consumers to perform such home taping. The Supreme Court's ruling in *Sony Corp. of America v. Universal City Studios, Inc.*, 464 U.S. 417 (1984) that such "time shifting" was fair use under US copyright law and that VCR manufacturers were not liable for copyright infringement was a significant factor in the commercial success of VCRs. The decision was reportedly a close one.[28] Had the decision been the other way, it is likely that the industry would not have developed as it did.

d) Technological design critical to VHS standard

Standards strategies were a central reason for the success of VHS as it was being introduced. This should not detract from the importance of the VHS design in shaping the standard and attracting support, and the interaction between technology development and standardization. There were important differences in technical performance and market philosophy between the formats before they were

[28] Samuelson 2006; Volk 2008.

presented to MITI and the other manufacturers for approval.[29] It is often claimed that Betamax was technically equivalent or superior to VHS and lost the contest because of JVC's superior licensing strategy in attracting other manufacturers.[30] This glosses over the fact that VHS was also more suited to the needs of a mass consumer product for manufacturing and use. These were decisive factors in attracting other manufacturers to VHS as the one with the most customer appeal and in the subsequent market competition.

Sony's Betamax had adapted a compact version of the U-matic industrial VCR, introduced in 1971, for a consumer product. JVC had collaborated with Sony on U-matic and followed a similar technology. However, having been shown Betamax prototypes by Sony in 1974, JVC believed changes were needed for an effective consumer product and continued to develop its own additional technologies for VHS. Technical differences included a simpler "M-loading" tape mechanism compared to Betamax's "U-loading" system, and circuit developments that jointly enabled a smaller, lower-cost machine with longer playback time.[31]

Far from being cost-cutting exercises, these were part of a complete systems approach by JVC with features that it considered necessary for a successful consumer VCR. Contrary to popular history and Sony's claims, differences in the two formats' picture quality may have been minor and not significant to consumers.[32] Considering the whole product, the additional features made VHS superior.

The interaction between development and standardization continued after the formats had been introduced. There were many technical and marketing innovations as firms played cat and mouse to try to get ahead of their competitors with new features. These included longer playing times, front-loading for Betamax, freeze frame and fast rewind/forward, remote control, and time shift programming.[33] These improvements built on the initial design to further develop the standard. Some came from licensees, though most were developed by JVC itself. Although Betamax ended by matching VHS's advantages, it could not overcome VHS's momentum. VHS became the leading platform for further developments of video recording technology and helped transform the content industries.

e) Standards and profitability

Although VHS overcame Betamax as a standard, this might not mean that JVC's strategy was optimal, or that Sony's was a failure. This depends on whether JVC could not have expected to earn higher returns with any other strategy and whether Sony's result was due to its strategies, not chance. JVC's open strategy ensured the success of VHS, but this was at a cost of sharing the market with several other manufacturers. Could JVC have earned more by adopting an exclusive standard and facing Sony directly? Or by joining Sony with Betamax? Similarly, was Sony's exclusive strategy the best it could have done in the circumstances, even though it eventually had to abandon Betamax?

For JVC, the open strategy seems to have been optimal. In 1974, it was a relatively unknown company with most of its sales in audio equipment. It was much smaller than Sony, without its financial and manufacturing resources, or its brand reputation and distribution channels. These could have been decisive advantages for Sony in a new market that in the first instance had to be convinced that VCR was

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[29] Bylund 2010.
[30] Sony 1996; Morita 1986. Cusumano et al. 1992 focus on strategic maneuvering of VHS supporters.
[31] Milestones 2006; Bensinger 1981. M-loading and U-loading wrap the tape around the helical scanning drum in different ways, with M-loading somewhat simpler and more compact. Circuit developments for VHS enabled data to be packed more densely on the tape.
[32] Sony 1996; Schofield 2003.
[33] RCA's marketing skills are noted as an advantage for VHS in the US in directing further features.

a viable product.

Even though VHS was preferred to Betamax in customer acceptability and cost, alone JVC would not have been able to establish VHS before Sony could catch up. The open standard ensured adequate levels of manufacturing and market acceptance, the keys to VHS's success. Further, although it licensed many competitors, JVC managed to retain control of a large portion of the market. It did so not by placing restrictions on its licensees but by constant product improvement, keeping it ahead of its collaborators and expanding the market. Its partners left most of the technical innovation to JVC, concentrating instead on manufacturing and marketing. This was an impressive combination of openness and innovation leadership to maintain dominance of a still-growing market.

Turning to Sony's strategy, would it have done better to have used a more open strategy for Betamax from the beginning? Should it have switched to VHS as soon as it became apparent that Betamax had little chance of surviving in the long run? If it had matched JVC by making its own standard freely available from the beginning, it might have been able line up as many manufacturers as JVC. If it had not rushed a proprietary format, it might have developed a more widely acceptable product. This could have neutralized JVC's strategy. With Betamax and VHS competing on similar terms, Sony's market strength could have prevailed. Sony might then have been in JVC's position, with a large share of the world market, a continuing income stream, and licensing earnings.

The question is whether this was likely. A problem was not just that Sony's approach was one sided, but that Betamax design had fundamental problems. Given the reservations about the recording time and equipment size, in 1974 it might have been difficult for Sony to have attracted supporters on any terms. Conversely, Betamax might not have reached market in the form it did had Sony been convinced of the need for broad support. Even in 1974, there was time for product redesign before the arrival of VHS, two years later. Instead Sony thought that it could force the issue, and took a high risk. It may have underestimated the importance of market acceptability and overestimated the importance of being first.

In this case, the open standard seems to have been optimal for JVC, and the opposite for Sony. That does not mean that it is always the case—it depends on the situation and the industry at the time.[34]

4.4 Lessons from the contest

a) Market strategies for standards

The VHS versus Betamax standards contest is one of the clearest examples of market strategies for establishing standards. It took place almost entirely in the market as alternative approaches competed to become the *de facto* standard. It demonstrates what may be needed to establish a successful standard and the likely fate of unsuccessful standards with poor support, niche markets, and stranded users. Factors at work for VHS included most of the factors in successful standards strategy, including building the installed base and cumulative sales, establishing credibility, satisficing the technological design, careful timing, sponsorship, forming alliances, penetration pricing, product preannouncements, and care in handling official standards bodies.

This also contrasts open versus proprietary strategies. In this case, JVC's open strategy was more effective than Sony's proprietary strategy in attracting broad industry support and establishing VHS's credibility. This was vital for the smaller JVC in building its installed base more quickly. VHS was able to overcome Betamax's initial advantages of an earlier introduction, alleged better picture quality, and

[34] For a counter example, one need look no further than the profitability of Apple in mobile communications and computing.

Sony's size and reputation. VHS was helped by its longer playback time (two hours versus Betamax's one hour) and simpler manufacture, lowering costs and prices. It was also launched with more careful consumer marketing, including efforts made by its licensees. It took time for Betamax to match these features—it soon did so and excelled VHS in some respects, but by then the market was rapidly converging on a single VHS standard. The strategy was also profitable to JVC. Apart from sharing the market, it effectively led further technological development and became a more substantial company.

One factor that has not been discussed much above is the unpredictable one: chance. There are several points at which the story could have turned out differently, but worked in VHS' favor—such as JVC's decision to restart work on VHS in 1972, Sony's demonstration of its prototype to JVC in 1974, Matsushita's decision to support VHS in 1977, and the US Supreme Court's close decision in 1984. It is wrong to call this a product of luck rather than perseverance and planning, but there were a number of critical points. This may help illustrate the occasional importance of small chance events in determining standards outcomes.[35]

In this case, JVC's open standard was highly successful in establishing the VHS format against Betamax and in expanding the total VCR market more quickly and extensively than if the standard had remained proprietary. It brought several manufacturers into the market to expand the supply, helped reduce production costs and consumer prices, and was the basis for the huge installed base of VCRs that supported other compatible devices such as camcorders and effectively created the market for pre-recorded movies. It was the forerunner for many other consumer electronics products, such as home video, and can credibly be said to have pioneered the future markets for DVDs and home viewing via other media such as the Internet.

This also ensured that the VCR market grew more rapidly than it might otherwise have done, to become one of the most successful consumer electronics products of all time. Technological competition via standards had great benefits not just to JVC and its supporters but also to the rest of the electronics industry, the film and TV industries, and consumers. What if JVC hadn't decided to go its own way and compete with Betamax? The VCR market would likely have grown more slowly under a proprietary Betamax standard and would not have progressed technically and commercially as quickly or as far as it did.

b) Standards and technology development

The case also shows that standards should be seen within the context of other economic factors, especially technology development. The standard formats were the medium for coordinating innovation by Sony, JVC, and Matsushita. They formalized the technical designs and ensured that all products would be compatible. Note also that when licensing its technology to others, JVC was not constrained by prior conditions attached to the standard, as it might have been had there been a FRAND commitment. MITI left the market to decide. In this case, JVC almost automatically chose a liberal licensing policy.

The VHS versus Betamax standards contest was as much about establishing a dominant design for a new product as compatibility. Network effects were very important, on the supply side to make manufacturing capacity available and on the demand side being able to share tapes between machines. But a key characteristic of the winning VHS format was that it fit consumer needs better. Compatibility meant that eventually a single design would prevail, but an approach to understanding the contest that focused only on compatibility would miss the competing technology development that went on beforehand. For example, if Betamax had been established as a dominant standard, there would still have been compatibility, but arguably the design would not have been as successful as VHS.

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[35] Arthur 1989.

c) General indications

This may illustrate some general lessons for standards development. First, for new technologies at least, the development of standards is unlikely to be a simple case of selecting between alternatives. The alternatives often do not yet exist—they have to be developed to create the standard. Developing an acceptable format became the focus of innovation for VHS, to develop the features needed for a successful product and to convince other manufacturers. JVC and the manufacturers acted as standards developers, not standards setters. This distinguishes standards development and standards setting.

Second, for new products, technology development may continue long after the initial standard is introduced, with enhancements and expansion into adjacent markets. The original VHS standard became the basis for important further developments to the standard and in complementary products such as camcorders and accessories.

Third, being adopted as a standard does not necessarily translate into market success. It was not enough that both Betamax and VHS had been adopted as "official" standards and were backed by MITI. Philips' Video 2000 was also accepted as a standard by European manufacturers and reportedly technologically superior in some ways, but could not compete with VHS. Products still have to be accepted in the marketplace, and other competing standards may win that contest.

Fourth, the case shows that standardization should not be seen as a separate activity to be "added in" once technologies are developed. Standardization should be seen within a wider picture of interactions between technology development, product development, standardization, production, and market growth. In this case, JVC handled the combination of activities more effectively than Sony.[36]

5. Case Study 3: Wireless Communications Standards

5.1 Introduction

Over the past 30 years, communications industries have been transformed. They have grown rapidly to become some of the largest in the world and sit at the heart of an information revolution affecting almost all industries. Modern communications networks combine wired, wireless, and optical communications. Major sectors of information and communications technology (ICT) are converging as telecommunications, computing, and media share technology and operate across multiple platforms. These changes have relied strongly on standardization to coordinate technological innovation and ensure devices and services interoperate.

This section discusses the development of recent standards in two areas: computer network communications and mobile communications. These have relied primarily on two major international SDOs: the Institute of Electrical and Electronics Engineers (IEEE) for wired and wireless network standards, and the 3rd Generation Partnership Project (3GPP) for mobile communications standards. The reliance on formal standards organizations reflects the significance of the communications industries and the need for reliable global agreements and consistent processes. This has been combined with huge private investments in technological innovation and various forms of market competition as candidate technologies jockey for position in standards contests. Given the need for speed and flexibility in standards development for new technology, firms often have used industry alliances to develop technologies and then brought these to SDOs for formal standardization.

[36] There are other cases, such as analog HDTV and digital audio tape (DAT) in the 1980s, where standardization strategies may have been adequate in themselves but the product was not appropriate for the market at that time. OTA 1990; Farrell & Shapiro 1992; Grindley 1995; Shapiro & Varian 1998; Eargle 1992; Cross 2017.

Section 5.2 reviews potential standardization processes for combining markets and organizations in standards development, as a prelude to the communications case studies. Sections 5.3 and 5.4 then consider the two communications case studies, for computer network standards in IEEE and mobile communications standards in 3GPP. We find that many, though not all, network standards developed within IEEE have relied on standards first partly developed privately via consortia, with the SDO essentially completing the work needed to develop these as formal global standards. In other cases, IEEE has taken the initiative to unify what threatened to become fragmented private standards. The development of mobile communications standards has more consistently been governed by the SDO 3GPP throughout as the forum for coordinating technology development and interoperability standards. This may reflect the overriding importance of unified standards in mobile communications that require large interlocking investments in development, manufacturing, and infrastructure.

5.2 Standards processes – combining markets and organizations

This section outlines general factors affecting communications standards developed as a hybrid between private and formal standards and those developed primarily within SDOs. Hybrid processes are a feature of some computer network standards, while mobile communications standards are developed mostly within formal standards organizations.

Communications technologies need design and interoperability standards early in their development cycle to build credibility and avoid wasteful duplication of R&D and implementation effort. A problem is how to organize this to keep up with the pace of technology change while allowing for the lead times and high investments in development and manufacturing. A distinguishing feature of some communications is the additional need for long-term investments and planning for the rollout of infrastructure. This applies primarily to mobile communications and telecommunications carriers but may overlap with other standards such as WiMAX when these also depend on wide-scale networks.

There are two main paths by which communications standards are developed. In the first path, technologies may be developed privately with the guidance of a small group of developers and implementers in private alliances or interest groups acting as consortia. This allows rapid and responsive development, but support for the standards may be limited to the immediate sponsors. Support may be increased by extending consortium membership or otherwise attracting firms. This is time consuming and, unless the standard is very attractive, may not be credible, for reasons discussed above. An alternative is hybrid standardization: to bring the private design to an SDO to complete formal standardization once the basic technology is developed. For example, Ethernet, FireWire, and Bluetooth computer communications standards were developed largely privately but then standardized via an SDO (IEEE). In the earlier stages of development, there may be several competing technologies with their own consortia. Formal standards can help weed these out. They also help sponsors commit credibly to open licensing programs to attract adopters by making FRAND commitments or placing essential IP in patent pools.

In the second path, the need to involve a wide range of firms in the industry throughout the technology development and standardization process means that standards may be developed within an SDO from the beginning. This typically applies to regional or global mobile communications standards, or to major advances in an area, such as Wi-Fi and WiMAX network standards, in which the scale of adoption and the dangers of fragmentation discourage individual development.

SDO standards may also help firms develop the standard and technology concurrently, by forming a consensus among developers, implementers, and service providers. Standardization is often anticipatory, before products are introduced and before major investments by the parties, so that standardization can be coordinated with innovation. There is still likely to be significant R&D ahead of time as developers compete for a head start, and during the standardization process as the technology converges to a dominant design. Technology is also likely to be developed further as generational standards are enhanced.[37]

SDOs and many consortia also certify independent conformance testing organizations, which verify that a product complies with a given standard. Credible certification is vital. A product that is even part-compliant may not be useable in all conditions, and buyers will avoid it.[38]

Credibility within the industry is critical for communication standards because of the investments and time scales involved. As a result, SDO standards may be more credible than either *de facto* or consortia standards, since the debate between alternatives needs to be resolved by consensus before the standard is adopted and before products are brought to market. This does not mean that an SDO standard will automatically be adopted by the industry. There may be other competing standards, or the product may not be successful on the market.

A concern about the increasing use of hybrid standardization has been that SDOs might be reduced to confirming *de facto* private standards rather than being original developers. They have altered their procedures to reduce this risk and be more effective in their "large-scale" role. Many SDOs have sped up their procedures and may cooperate earlier with other standards organizations to avoid duplication and the risk of conflicting standards.[39] They may also offer other standards-related services such as advertising, education and training, and business research.[40]

5.3 IEEE communications network standards

a) IEEE standardization history

The Institute of Electrical and Electronics Engineers (IEEE) is a professional association formed in 1963 from the amalgamation of US associations going back to the nineteenth century.[41] It is the world's largest association of technical professionals, with more than 400,000 members around the world. One of its many functions is to develop global standards in a broad range of industries.

IEEE is one of the most important global standards development groups in electronics and electricity. Its involvement in electrical standards dates back to 1890, when the first US electrical standards were developed.[42] Its standards development has been managed by the IEEE Standards Board since 1963,

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[37] The complexity of communications systems means that a design may combine modularized components and be versatile enough to adapt as applications shift. This implies that interoperability is already part of the technology design. A new device is a system in itself.

[38] Some standards may acquire legal standing if they are specified in procurement contracts or national licensing. Some telecommunications standards may be specified in international treaties, such as those traditionally overseen by the ITU, or be a condition for obtaining a mobile communications license (as GSM standard was originally in Europe). The formal SDOs are part of the hierarchy of international standards organizations and are the route by which a standard may become adopted as a global standard by the ITU or ISO/IEC.

[39] Procedures in SDOs have been made more flexible and faster, such as "Alternative Approval Process" fast-track approval procedure introduced by ITU in 2001. There is now also more collaboration with forums and other SDOs to avoid duplication of work and the risk of conflicting standards in the market place. ITU 2006; Hazucha 2013; http://www.itu.int/en/ITU-T/about/Pages/approval.aspx

[40] https://www.bsigroup.com/en-GB/standards/benefits-of-using-standards/ ; https://www.ansi.org/about_ansi/faqs/faqs

[41] http://ethw.org/IEEE_History; The earliest parent association was the American Institute of Electrical Engineers (AIEE) formed in 1884. http://ethw.org/AIEE_History_1884-1963

[42] http://ethw.org/IEEE_Standards_Association_History

reorganized as the IEEE Standards Association in 1985.[43] Technically IEEE is neither SDO nor consortium, but a "community" of individual members, although it functions effectively as an SDO. It is associated with SDOs such as ANSI and ISO/IEC, and IEEE standards often become formal US and international standards.[44] IEEE standards are implemented voluntarily by firms, relying on the credibility of the IEEE process. They may acquire legal standing if adopted as formal international standards or specified in regulations or contracts.[45]

IEEE standards apply in a wide range of applications. IEEE members are individual professional engineers, not firms, and its standards tend to focus on particular technologies rather than industries. Mobile communications standards, by comparison, are developed within specialized telecommunications standards organizations whose members are organizations active in that industry, including technology developers, device and equipment manufacturers, and telecommunications carriers, as well as representatives from application services and regulators.[46]

b) Overview of IEEE communications standards

Network communications standards are developed within the IEEE 802 Local Area Networks (LAN)/Metropolitan Area Networks (MAN) Standards Committee. Standards include the IEEE 802.3 wired Ethernet standard, IEEE 802.15 Bluetooth, IEEE 802.11 wireless local area network standard ("Wi-Fi"), and IEEE 802.16 wireless metropolitan area networks ("WiMAX"). Computer communications networks involved range from small-scale personal area networks (PANs) used at short range to join a phone or headset to a computer at low power up to the global internet. In between are LANs of computers and peripherals within an office, and MANs operating on a citywide scale. On a still larger scale, wide area networks (WANs) include national and global telecommunications and mobile networks, and large private business networks.

Communications networks may use combinations of wireline, wireless, and optical cable. Many were originally designed around wired connections (Ethernet and telecommunications) and have been extended to wireless (Wi-Fi and mobile phones) or optical fiber (MANs and mobile communications backbone) as these technologies have become more cost effective and pervasive. Also, the technologies used by different communications networks are merging, as telecommunications networks increasingly use computer-based technology and larger computer networks use backbone long-distance transport from telecommunications.

Different standardization routes have been in use depending on technology and the breadth of its support. In some cases, two-step hybrid standardization may be a feasible route for smaller-scale systems and untried concepts. Developers may require IEEE standards for credibility with implementers and consumers but may develop the technology privately before submitting it to the SDO. For nascent technologies such as Ethernet, FireWire, and Bluetooth, the technology and the standards were first developed privately in single firms, working groups, and consortia. Speed to market was important, and the technology may have been too new to predict its future. Specifications were brought to the SDOs for

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[43] http://ethw.org/IEEE_History ; http://ethw.org/IEEE_Standards_Association_History ; http://standards.ieee.org/about/ieeesa.html

[44] IEEE-SA is not a body formally authorized by government, but a self-organized "community." Formally recognized international standards organizations (ISO, IEC, ITU, CEN) are federations of national standards bodies (American ANSI, German DIN, Japanese JISC, etc.).

[45] http://www.eng-tips.com/viewthread.cfm?qid=102915 ; https://www.ieee.org/education_careers/education/standards/standards_glossary.html

[46] In February 2015, IEEE adopted controversial changes to its IP policies, placing increased conditions on licensing of standards essential patents. Teece & Sherry 2016.

formal standardization when early products were already on the market.

In other cases, for more far-reaching technology it may be important to involve a whole industry earlier in standardization and use SDOs from the beginning. This was seen with the IEEE WLAN/WMAN standards like 802.11 Wi-Fi and 802.16 WiMAX, which were developed within the SDO process and focused previously fragmented proprietary development efforts. They have been regularly enhanced since then.

c) Individual standards

i) IEEE 802.3 – Ethernet

Ethernet standards were first developed privately and only formally standardized once the broad potential of Ethernet was realized. Formal standards helped its acceptance, and it is now the most widely installed wired LAN technology.

Originally developed by Xerox in 1973, the first "DIX" standard developed by Digital, Intel, and Xerox appeared in 1980.[47] Formal standardization resulted in the publication of IEEE 802.3 in 1983. Ethernet initially competed with two LAN proprietary systems, Token Ring and Token Bus, but by the late 1980s Ethernet had become dominant. Approval of Ethernet on the international level was achieved with the ISO 8802-3 standard published in 1989.

Initially designed to run over coaxial cables, Ethernet now typically uses twisted pair or optical cable. It has become a family of IEEE 802.3 enhanced standards developed since then. These are steadily evolving to embrace new media, higher transmission speeds, and changes in frame content. [48]

ii) IEEE 802.15 WPAN – Bluetooth/ZigBee

Bluetooth is a wireless technology used to replace wires over short distances at low power, such as for connecting devices to mobile phones and building wireless personal area networks (WPANs). Bluetooth was developed privately by Ericsson in 1994 as a wireless alternative to data cables. It was only submitted to become a formal standard some years later. Aided by formal standardization, Bluetooth is now gaining widespread use in applications calling for flexible, short-range, low-power wireless connections. It is likely be an important component of the Internet of Things (IoT) for low-power applications.[49]

Bluetooth was standardized within the IEEE 802.15 Working Group for Wireless Specialty Networks (WSN) as IEEE 802.15.1 in 2002 and 2005. [50] IEEE no longer maintains enhancements of the standard. Maintenance of the standard has returned to the Bluetooth Special Interest Group (SIG), a private alliance of firms set up in 1998 to promote and administer the standard. [51] The SIG is believed to be

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[47] Ethernet, like Wi-Fi later, owes its origins to ALOHAnet computer networking system, developed at the University of Hawaii in the 1970s. Although designed for wireless or satellite transmission, ALOHAnet could also use cable. Yu 2013; http://timeline.ethernethistory.com/

[48] E.g., 802.3ac to accommodate VLAN and priority tagging and functional requirements (e.g., 802.3af, defining Power Over Ethernet [POE] crucial to most Wi-Fi and IP telephony deployments) http://searchnetworking.techtarget.com/definition/Ethernet

[49] Curry 2016; RS Components 2015.

[50] http://www.ieee802.org/15/pub/TG1.html ; http://standards.ieee.org/findstds/standard/802.15.1-2002.html ; http://standards.ieee.org/findstds/standard/802.15.1-2005.html

[51] https://www.bluetooth.com/about-us This is similar to the USB Implementers Forum (USB-IF) set up to promote the USB standard. Similar alliances have been set up for Wi-Fi, WiMAX, and others. Possible reasons for such a change may be that further developments are linked to commercial issues and an SDO may not be an effective location to manage this once the initial standards are developed. In this case, IEEE 802.15 working group has

better suited to manage the commercialization and further development of the standard.

IEEE 802.15 continues to develop standards for other types of wireless networks. ZigBee is another WPAN wireless connection standard designed for small-scale projects, such as home automation and medical device data collection. It aims to be simpler and less expensive than other WPANs such as Bluetooth or Wi-Fi. It was conceived by IEEE working groups in the 1980s and standardized as IEEE 802.15.4 for low-rate wireless personal area networks (LR-WPANs) in 2003, revised in 2006. It is promoted by the ZigBee Alliance.[52]

iii) IEEE 802.11 WLAN – Wi-Fi

Formal IEEE Wi-Fi standards helped resolve the potential fragmentation of private standards for wireless network technology. This helped establish Wi-Fi as the major wireless local area network (WLAN) technology.

WLAN technology was initially developed privately, but these were limited systems with fragmented private standards. It took an SDO, IEEE, to realize that a universal open standard was needed for the industry to grow. The success of this strategy is shown in the widespread use of Wi-Fi today and the expanded use predicted for the future.

This is standardized in the IEEE 802.11 set of standards for computer communications, marketed as Wi-Fi. The original version of IEEE 802.11 was released in 1997 and has been extended and amended in a number of revisions since then. Wi-Fi standards (IEEE 802.11a, b, g, n and now ac) define the equivalent of Ethernet for WLANs.[53] In 1999, the Wi-Fi Alliance was formed by industry members to promote WLAN under the Wi-Fi trademark.[54]

Wired Ethernet and wireless Wi-Fi are the most common transmission technologies for LANs.[55] Both have origins in ALOHAnet, a basic radio data network developed in 1971.[56] WLANs were made commercially feasible by the 1985 US Federal Communications Commission (FCC) ruling that released spectrum in the industrial, scientific, and medical radio (ISM) band for unlicensed use. Early WLANs had limited performance and were expensive private networks with proprietary protocols.[57] In the early 1990s, the IEEE realized that an open wireless standard was necessary and established the 802.11 working group to develop a wireless LAN standard.[58] In 1997, it released the first 802.11a/b standards. Subsequent enhancements increased the speed from the initial maximum data transfer rate of 2 Mbits/s for 802.11a, b to 600 Mbits/s for 802.11n in 2009, and 1.3 Gbits/s for 802.11ac in 2013. 802.11 standards have also been extended into new spectrum bands.[59]

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focused its efforts subsequently on other WPAN standards.

[52] http://www.zigbee.org/

[53] Kreuzer 2017; http://ethw.org/Wireless_LAN_802.11_Wi-Fi

[54] Wi-Fi is "Wireless Fidelity." http://www.wi-fi.org/who-we-are/history

[55] Kurose & Ross 2000; http://www.ieee802.org/ ; http://searchnetworking.techtarget.com/definition/Ethernet

[56] Abramson Schwartz 2009.

[57] In 1988 NCR Corporation (acquired by AT&T in 1991) introduced a precursor to 802.11, called WaveLAN. Null 1999; Tourrilhes 2003; Bray 2014.

[58] This effort was led by Vic Hayes, who helped establish and chaired the IEEE 802.11 working group from 1990-2000, and is often called the "father of Wi-Fi." Charny 2002; Kharif 2003; Kreuzer 2017; https://www.computer.org/web/awards/karlsson-victor-hayes

[59] Kreuzer 2017. Beginning in 1991, a European alternative known as HiperLAN/1 was also pursued by the European Telecommunications Standards Institute (ETSI), with a first version approved in 1996. A second HiperLAN/2 specification appeared in 2000. Neither achieved the commercial success of 802.11, although much of

Future developments of 802.11 will further increase speeds and add new spectrum bands. Wi-Fi communications are also converging with mobile communications to extend both services, with Wi-Fi hotspots potentially a large part of future plans for 4G and 5G systems and Wi-Fi connections switching to 4G/5G automatically when on the move. Future developments to 802.11 will be steered by IEEE, but there is likely to be increased coordination with other technologies such as 5G LTE and small cells.[60]

Bluetooth and Wi-Fi have some similar and related applications.[61] Bluetooth is used for connecting devices and transferring data at short range. It was originally intended for portable equipment but also works for fixed applications such as home thermostats. Wi-Fi is a more comprehensive replacement for high-speed cabling for WLANs. Significantly, it can be fixed or mobile. Bluetooth and Wi-Fi are to some extent complementary. Bluetooth works well in simple applications to connect two devices with minimal configuration. Wi-Fi applies for more complex WLAN configurations and when high speeds are required. Both have scope for future development.

iv) IEEE 802.16 WMAN – WiMAX

WiMAX was initiated by IEEE essentially as an extension of Wi-Fi to longer distances and larger networks. Although the standard has been successful its use has been limited by parallel developments of other mobile communications technologies. WiMAX was a contender for 4G mobile standards but was rejected in favor of Long Term Evolution (LTE), which had broader support, especially from carriers. This may illustrate how standardization does not guarantee commercial success. WiMAX still has a number of applications and may be part of 5G wireless communications systems.

Wireless metropolitan area networks (WMANs) are similar to WLANs but operate over longer distances and larger geographic areas.[62] Where Wi-Fi provided a wireless alternative to Ethernet LANs, WMAN, commercialized as WiMAX, has been seen as a viable last-mile alternative to expensive telecommunications links between offices and to the Internet.[63] The first standards, IEEE 802.16, were published in 2001 for fixed point-to-multipoint broadband wireless systems. Capabilities have been extended regularly. Non-line-of-sight and a range of up to 30 miles were added with 802.16a in 2003. Mobile connections were added with 802.16e in 2005. The current standard 802.16.1a-2013 enables an array of interworking with other communications systems such as LTE and others. WiMAX initially provided around 30 Mbps data rates and currently provides up to 1 Gbit/s for fixed stations.

Although IEEE 802.16m WirelessMAN-Advanced was a candidate for 4G, it was overshadowed by LTE-Advanced, discussed below. It remains a complement to LTE and will play a part in future communications developments, at the least for broadband connections in remote areas.

WANs include national and global telecommunications and mobile communications networks, as well as large private business or educational networks. These deliver data in the form of telephone calls, broadband, and streaming video. A user with a laptop may search the Internet, check email, or connect to a virtual private network (VPN) using a WAN. Most computers now have integrated Wireless WAN (WWAN) capabilities. WWANs use a combination of mobile communications cellular network technologies such as LTE, WiMAX, UMTS, CDMA2000, GSM, cellular digital packet data (CDPD), and

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the work on HiperLAN/2 survived in the physical specifications for IEEE 802.11a. Lemstra, Hayes & Groenewegen 2010.

[60] Miller 2014

[61] US Robotics 2006.

[62] http://searchmobilecomputing.techtarget.com/definition/80216

[63] WiMAX is "Worldwide Interoperability for Microwave Access." The WiMAX Forum, a private alliance established in 2001, promotes WiMAX and oversees certification of compliant devices. It describes WiMAX as "a standards-based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL."

Mobitex offered by wireless service providers. They may also use Wi-Fi to provide Internet access via hotspots if available.

5.4 3GPP mobile standards

a) Mobile communications and standardization

The leading global organization developing mobile communications standards today is the 3rd Generation Partnership Project (3GPP).[64] This partnership of seven telecommunications SDOs was formed in 2000 to develop standards for the next-generation wireless network.[65] 3GPP became the industry standards forum that defined third-generation (3G) UMTS standards and more recently fourth-generation (4G) LTE. It is now focused on developing 5G standards.

The mobile communications industry and the technologies and standards supporting it have developed rapidly since the first-generation (1G) analog phones appeared in the 1970s.[66] Digital technologies were introduced in the early 1990s and have evolved through a constant stream of standards since then, including 2G, 2.5G, 2.75G, 3G, 4G, and the current development effort to develop 5G.

The 1G mobile phones of the 1970s and 1980s used analog signals with a dedicated frequency for each call. They were heavy, expensive, and not compatible across countries. Even so, they were very successful, and the market grew rapidly.

New digital technologies in the 1980s provided the opportunity to expand mobile capacity with better spectrum use, lower costs, and common standards with international roaming. The industry moved towards a common set of 2G standards to reduce development risk and to improve consumer access. In Europe, the European Conference of Postal and Telecommunications Administrations (CEPT) began work to define a single digital 2G standard in 1982.[67] It established the Global System for Mobile Communication (GSM) standard in 1987, using time division multiple access (TDMA) digital processing. Standardization was transferred to the newly formed European Telecommunications Standards Institute (ETSI) in 1988, and the first 2G GSM phones appeared in 1991.

The US developed a separate TDMA D-AMPS digital 2G standard in 1990. The main competitor to GSM was from Qualcomm, which developed a proprietary system based on code division multiple access (CDMA). This is more spectrum efficient than TDMA, but the two are technically incompatible. It was standardized in the US in 1995 by the Telecommunications Industry Association (TIA) as IS-95 and introduced that year as cdmaOne. In the standards contest, cdmaOne shared the market in US, Japan, and Korea, but GSM was dominant in Europe and increasingly present worldwide, including in the US. GSM's early start and installed base gave it strong advantages and restricted cdmaOne growth despite CDMA's technical performance. There have been many enhancements to GSM, starting with SMS texting in 1991.[68] The most widely adopted 2.5G standard was the General Packet Radio Service (GPRS) standard, originally developed by ETSI and now maintained by 3GPP. The most widely adopted 2.75G

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[64] Many different SDOs have been involved in setting telecommunications standards. Global leaders include the International Telecommunication Union (ITU), ETSI, IEEE, and many regional and national SDOs and SSOs.

[65] The seven 3GPP Organizational Partners are: The Association of Radio Industries and Businesses, Japan (ARIB), The Alliance for Telecommunications Industry Solutions, USA (ATIS), China Communications Standards Association (CCSA), ETSI, Telecommunications Technology Association, Korea (TTA), and Telecommunication Technology Committee, Japan (TTC), and (since 2015) Telecommunications Standards Development Society, India (TSDSI). http://www.3gpp.org/about-3gpp/about-3gpp

[66] The first company to produce a handheld mobile phone is usually reckoned to be Motorola in 1973. Shiels 2003.

[67] Hillebrand, Rosenbrock & Hause 2012; https://update.revolvy.com/main/index.php?s=GSM%20network&item_type=topic

[68] http://www.gsmhistory.com/sms/

standard was Enhanced Data Rates for GSM Evolution (EDGE). GSM and its 3G/4G successors UMTS/LTE have been extremely successful as the most widely used cellular technology in the world today, with 90 percent market share, operating in over 200 countries.[69]

The industry started developing 3G systems in the late 1990s to provide increased data capacity to meet the growing demand for voice and nascent mobile broadband services. Building on the success of GSM, six international SDOs (now seven) formed the 3GPP in about 1998 to develop more advanced mobile communications standards based on GSM networks but incorporating CDMA technology, called UMTS/WCDMA. Another group formed the 3rd Generation Partnership Project 2 (3GPP2) to develop global standards for CDMA2000, an evolution of CDMA IS-95. This led to a "public" 3G standards contest between Ericsson and Qualcomm, between what was characterized as an evolution of GSM though using different core technology, and an evolutionary CDMA-based standard.[70] The IP part of this dispute was resolved by cross-licensing in 1998, but the development of two standards in 3GPP and 3GPP2 continued in parallel. The most widely used 3G standard today is UMTS/WCDMA, although the underlying CDMA technology is common to UMTS and CDMA2000.[71] There have been a series of enhancements to 3GPP standards, discussed below.

By 2008, the need for ultra-fast broadband access, driven by the growth of smartphones, mobile internet, and applications such as streaming media, threatened to outstrip the capabilities of 3G.[72] ITU IMT-Advanced requirements set targets for 4G standards, with peak speeds of between 100 Mbits/s and 1 Gbit/s, according to mobility, compared to the peak data-rates of 1 to 5 Mbits/s for 3G. 4G systems were also to be based on all-IP (Internet Protocol) packet-switched networks, ideal for data, and a paradigm shift away from circuit-switched voice to packet data in future.[73] The industry started to develop two competing 4G systems, both based on orthogonal frequency-division multiplexing (OFDM) technology.[74] These were WiMAX, standardized by IEEE, and LTE, standardized by 3GPP. This parallel development led to another standards competition between LTE and WiMAX.[75] Both had technical strengths, and WiMAX was available earlier that LTE. However, LTE had the critical advantages of being an evolution of existing 3G standards and being supported by most of the network operators. Network operators are currently rolling out LTE and LTE-Advanced 4G systems.

With enhancements to 4G standards still ongoing, the industry has started preparing for 5G communication systems planned for 2020.

The evolution in mobile communications has been one of the most fundamental economic and technological breakthroughs of recent decades. It has transformed the bulky carphones of the 1970s into the powerful and, relatively speaking, inexpensive smartphones and tablets today. A new mobile

[69] Hillebrand, Rosenbrock & Hause 2012; http://www.gsma.com/aboutus/gsm-technology/gsm

[70] Qualcomm 1999; Grindley, Salant & Waverman 1999; Hjelm 2000; Saugstrup & Henten 2006; http://www.ericssonhistory.com/changing-the-world/Big-bang/A-new-fight-/

[71] In a necessary compromise, the ITU IMT-2000 global standard for 3G in 1999 permitted six possible radio interfaces: EDGE (evolution of GSM/GPRS); CDMA2000 (3GPP2); three versions of UMTS: W-CDMA (ETSI), TD-CDMA (ETSI), TD-SCDMA (Chiba); DECT (portable phones); and WiMAX. http://opensource.telkomspeedy.com/wiki/index.php/IMT-2000

[72] Saeed 2010.

[73] Tellabs 2012.

[74] OFDM technology is well suited for transmitting large amounts of digital data via wireless. It works by splitting the radio signal into multiple smaller "sub-signals" that are then transmitted simultaneously at different frequencies to the receiver. OFDM reduces the amount of crosstalk in signal transmissions. Versions of OFDM are also used in optical cable and other systems. Molisch 2010, p. 417.

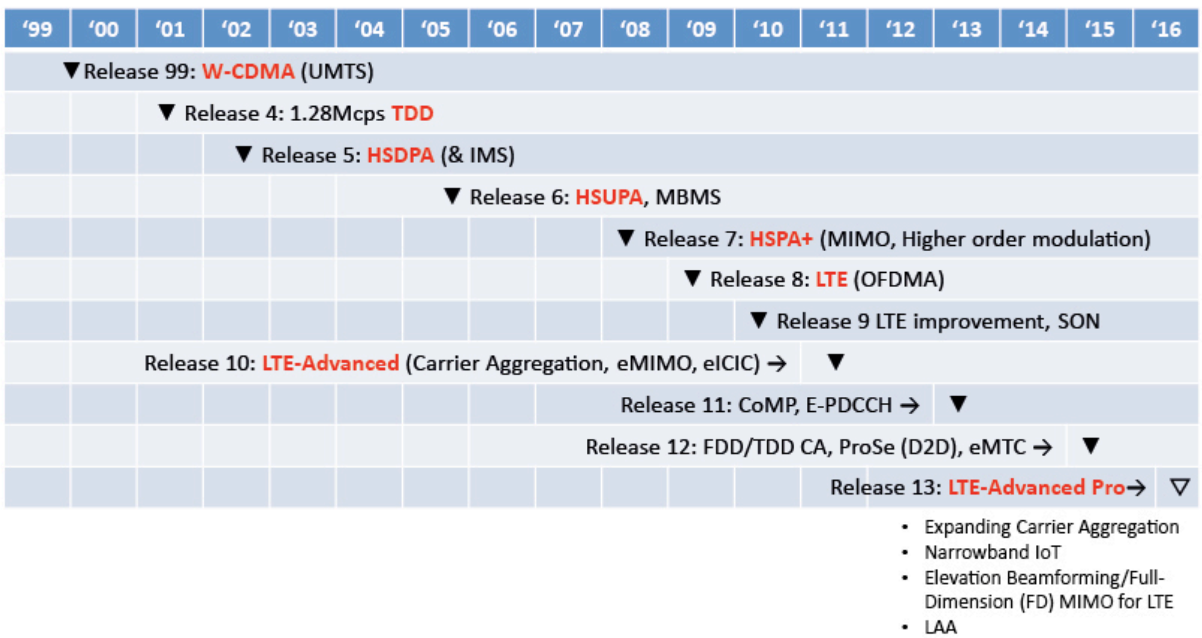
[75] Hamblen 2008; Tudan 2012; Aldmour 2013.

generation has appeared approximately every decade since the first digital systems were introduced in the 1990s, enabled by technological breakthroughs coordinated via standards. It has expanded beyond voice into broadband and internet to become the core communications hub for an array of services affecting all industries.

b) 3GPP standards generations

The evolution of wireless capabilities has taken place over several standards generations. A regular series of technical developments marked by successive standards revisions, every year or two, have built on the original 2000 3G/UMTS/WCDMA standards. These have added new capabilities and vastly increased performance, leading to the first 4G/LTE standards in 2008 and currently preparing for 5G. Successive releases build on previous generations, and each step represents a significant advance over the previous generation. Some of the headline 3GPP radio technologies and systems over the recent releases are shown in **Figure 4**.[76]

Figure 4: Generations of 3GPP standards releases



The main new features for each of these releases of the 3GPP standard for 3G and 4G are listed in **Table 4**. These include the growth in the data rates and other vital improvements.[77] The growth in the peak data rates is a key driver of growth of the mobile ecosystem. It has depended on combinations of multiple innovations and developments. Standards and innovations also apply to new components (DSP, sensors), new devices (smartphones, tablets), and new infrastructure (high data-rate multiple-input, multiple-output (MIMO) antennae, servers, small cells, hybrid networks).

Table 4: 3GPP standards releases

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[76] http://www.3gpp.org/about-3gpp

[77] Other advances include high transmission rates by packing multiple antennae in devices, power-saving, new services such as IP Multimedia Subsystem (IMS) and Quality of service (QoS), and seamless interoperability with Wi-Fi networks.

3GPP Release	Release date	Content
Release 99	2000	First UMTS standard: based on W-CDMA
Release 4	2001	1.28Mcps TDD, All-IP core network
Release 5	2002	Added HSDPA, IMS
Release 6	2005	Added HSUPA, MBMS, integrated with WLAN, GAN, PoC
Release 7	2007	Added HSPA+ (MIMO, HOM, etc.), EDGE Evolution
Release 8	2008	First LTE,: all-IP Network (SAE), OFDMA, FDE, and MIMO radio interface
Release 9	2010	LTE enhancements: WiMAX interoperability, Dual-Cell HSDPA, HSUPA
Release 10	2011	LTE-Advanced: IMT-Advanced 4G requirements, multi-cell HSDPA
Release 11	2013	Further LTE enhancements, detailed 4G LTE-Advanced
Release 12	2014	LTE-B: Wi-Fi integration, LTE-Hi hotspot and small cells, 3D beamforming
Release 13	2016	Further enhancement: 30x LTE capacity

The first standard recognized as 4G/LTE was Release 8, in 2008, which included all-IP Network (SAE), orthogonal frequency-division multiple access (OFDMA) coding, frequency-domain equalization (FDE), and MIMO radio interface. This was not yet true LTE-Advanced (LTE-A) meeting ITU IMT-Advanced specifications, but included fundamental changes and performance improvements compared to 3G. 3GPP Release 8 also introduced five LTE User Equipment (UE) categories depending on maximum peak data rate and MIMO capabilities support.[78] UE categories define combinations of uplink and downlink capabilities and broaden the standard to include various combinations of speed, power use, and other characteristics depending on the user equipment and the application.[79] This takes the technology into broader realms of applications where peak data rates are not the only consideration.

The first "true" 4G standard meeting ITU IMT-Advanced requirements was 3GPP Release 10, referred to as LTE-Advanced or LTE-A. This has been subsequently enhanced in Releases 11, 12, and 13. LTE-A is the evolution of the original LTE technology toward even higher bandwidths. It promises nearly three times greater speed than the basic LTE network and comprises five building blocks: Carrier Aggregation, Increased MIMO antennae, Coordinated Multipoint (CoMP), Relay Station, and Heterogeneous Network (HetNet). New UE categories have been introduced with each new Release, with a most recent count of 20 currently.[80]

LTE-A creates a bridge between 4G and 5G worlds.[81] Further 3GPP standards Releases are underway that will advance 4G and define 5G. A main concept in increasing the capacity of mobile communications to bring to 5G is to expand small-cell networks and create a super-dense network of tiny cells. Other pillars of 5G are likely to be high-capacity MIMO antennae and the integration with Wi-Fi cells. The goals of 5G technology can be summarized as: a 1,000-times increase in capacity, support for more than 100 billion connections and up to 10 Gbits/s speeds, and below 1ms latency. The first 5G standard is projected to be 3GPP Release 16 in 2020.[82] The structure, capabilities, and content of 5G and its timing are still evolving. In practice, it is more likely to be an evolution of previous 4G technologies than a clear breakthrough. Other developments based on mobile communications include IoT and integration of

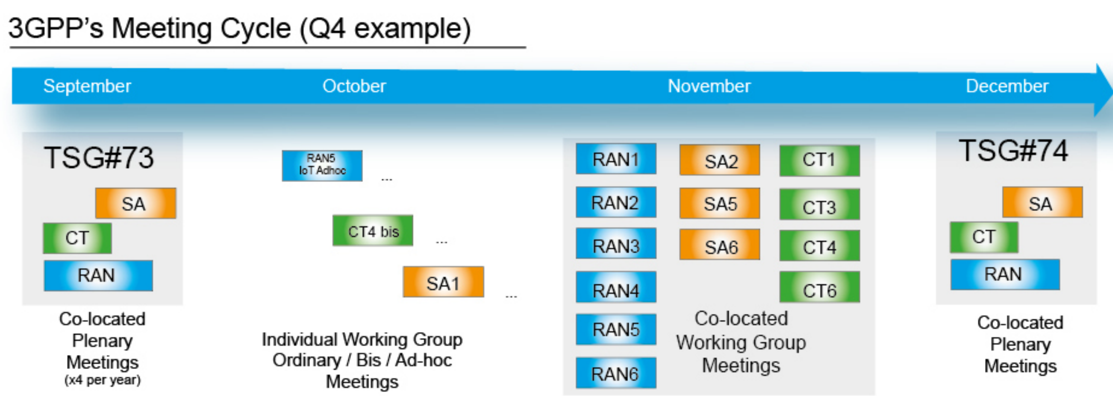
[78] http://www.radio-electronics.com/info/cellulartelecomms/lte-long-term-evolution/ue-category-categories-classes.php
[79] http://www.3gpp.org/keywords-acronyms/1612-ue-category
[80] Ghadialy 2017.
[81] A crucial part of LTE-A is HetNet, a gradual evolution of the cellular architecture, in a complex network as small cells that add hundreds or even thousands of entry points into the cellular system. HetNet is a multilayered system of overlapping big and small cells to pump out cheap bandwidth. Ahmad 2015.
[82] Romano 2016; Mallinson 2016.

mobile communications with Wi-Fi.[83]

c) Implications for mobile communications standards development

Mobile communications standards illustrate the parallel importance of technology development and interoperability. Each generation of standards has been driven by an important step in technology innovation. These have been coordinated via the development of SDO standards, primarily in 3GPP.[84] The standards development process begins when the standards plenary group steering committee sets general requirements for the next-generation standard and establishes working groups to coordinate work in these directions. Developer firms work within these groups to develop technology and to propose new designs to meet these aims. There follows a to-and-fro within the working groups whereby different proposals are sponsored, presented, evaluated, and further developed over a period of about 1.5 years. For a typical cycle of working group and plenary meetings for 3GPP, see **Figure 5**.[85]

Figure 5: 3GPP working group and plenary meeting cycles



The groups vote on proposals that eventually are reduced to a single proposal; if it passes the final vote (typically decided by consensus, or if necessary by a vote requiring approval by 71 percent of member organizations), it is sent to the governing council for adoption as part of the next standard.[86] The process is one of voluntary consensus. As proposals are reviewed and amended, some may be dropped altogether, others improved to meet concerns, and some amalgamated into joint proposals that others can support. The working groups involve representatives from member firms, including technology developers, device and equipment manufacturers, carriers, and applications and service providers.

The bulk of the technical proposals are made by a relatively small group of developer firms, with the other members contributing comments and keeping informed of the standards' progress.[87]

The main focus for standards generation is the drafting phase. Drafting takes place in stages of management, specification, validation, and testing, shown in **Figure 6**.[88] Feedback from the validation and testing steps is likely to require further development of the technology and standards by the

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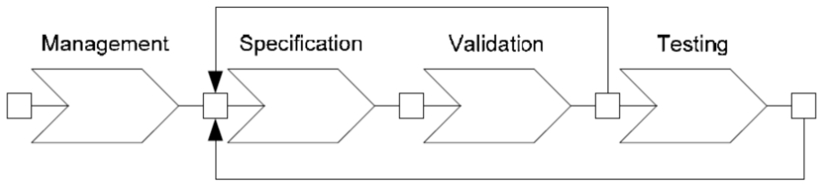
[83] Flore 2016.; http://www.3gpp.org/news-events/3gpp-news/1805-iot_r14
[84] For process summaries see Gupta 2013; Kang & Bekkers 2013; Teece et al. 2016; http://portal.etsi.org/Chaircor/process.asp
[85] http://www.3gpp.org/about-3gpp
[86] 3GPP 2016.
[87] Gupta 2013; Baron, Gupta & Roberts 2015.
[88] Van der Veer & Wiles (2008); Teece et al. 2016; http://portal.etsi.org/Chaircor/process.asp

member firms and 3GPP.

Figure 6: Drafting phases of the Standards Making Process (SMP) with feedback



Later stages of standardization include setting up the conformance testing requirements and certifying testing bodies, and promoting the standard. Testing and certification themselves take place outside the SDO, and may involve further feedback interactions between the SDO and member firms.

In general, the whole process of a new 3GPP standard takes about two years—with the initialization of succeeding releases overlapping each other by several months or more.

This helps illustrate the degree of coordination between technology development and standardization taking place via the SDO working groups.

6. Future developments in standards – where are we headed?

With the proliferation and rapid advance of digital communications, and the focus of many industries around these, the importance of standards in the future is likely to continue to grow. This will affect specific areas of communications standards. It is also likely to include the growing integration of information from many other industries using communications technology and further cross-collaboration and development. Given the rapidity of technological advances and the complexity of future applications, it is also likely that the trend toward greater use of private standards development, consortia, and faster hybrid standards processes between consortia and SDOs will continue. SDOs will continue to streamline standards development processes and diversify their services.

6.1 Communications standards and IoT

Wireless communications use has exploded over time, with billions of users using billions of devices to send uncountable numbers of voice and data messages annually. This progress seems likely to continue and accelerate. New developments such as 5G mobile communications and the Internet of Things (IoT) promise to extend interconnection between the different types of devices and services so that they interoperate seamlessly.

5G developments and their impact on standards are discussed above. The advances in wireless communications standards have been characterized by higher data transmission performance (e.g., higher throughput, speeds, use of different frequency bands), increasing range of applications (e.g., cellular versus WLANs), and the ability to serve greater numbers of simultaneous users in a given area. The total number of SEPs covered by these various standards is in the tens of thousands. The total R&D spending to develop these technologies is in the billions of dollars. Cellular carriers also spend billions of dollars in spectrum auctions to acquire the spectrum needed to implement these standards.

The IoT describes the connection of an increasing range of devices to the Internet, such as cars, kitchen appliances, electric meters, smart homes, and many others.[89] More devices will join the list as the IoT

[89] For introductions to IoT, see Wasik 2013; Meola 2016.

grows. A definition of IoT is "a network of internet-connected objects able to collect and exchange data using embedded sensors."[90] An objective is the use of the interconnected sensors to not just monitor but also control and make "smart" decisions based on the data. IoT standards are likely to be complex and difficult to develop as more devices are used by more users over an increasingly diverse range of applications. [91]

IoT is likely to vastly increase the scope of communications and integrate services in many industries. A challenge for IoT standards is that information exchange may be between widely different applications with different operational and communications needs. This may bring together fixed and mobile, low and high power, and applications ranging from occasional monitoring of sensors to real-time control of transport devices. An electric meter sensor might send information only periodically, once a day or once a month, and need low power to conserve batteries. A self-drive car needs instantaneous, high-volume, two-way data communications running in real time. Also, once separate, communications segments may become less distinct and overlap into other services running over other networks.

There are already many consortia and alliances working on aspects of IoT standardization.[92] This includes SDOs such as IEEE, 3GPP, and ITU, as well as numerous private consortia and alliances. [93] It is too soon to be concerned with the integration of different IoT standards, but this is likely to become an issue soon. The area is evolving quickly, and future directions are still being defined.

6.2 Other standards for convergence and integration

General trends in digital electronics are likely to be continued rapid and diverse innovation supported by equivalent standards development. Given the rate of change and simply the volume of standards, this may include increasing use of private consortia to coordinate innovation and interoperability. Consortia have advantages in that they may be less restricted by formal requirements and can focus on technical and market problems in flexible and responsive ways.[94] However, formal SDOs also have attractive features such as inclusivity, accessibility, and credibility. An increasing trend may be finding new ways to integrate the two routes.[95] Many SDOs have already streamlined their procedures to incorporate private standards into formal industry standards more quickly without sacrificing quality. Conversely, standards trade organizations may take over more responsibilities for maintaining standards once they have been established.

Equally significant may be the increasing use of communications to integrate different industries around individual and common data systems. Convergence is well underway focusing diverse industries around communications services. Some commentators put mobile communications at the hub of this "grand convergence" as more industries become more focused on digital information and rely increasingly on communications to interoperate with consumers and other industries.[96] IoT is one manifestation of this, as is e-Business. Such changes, should they occur, will significantly involve the development of

[90] Meola 2016.
[91] For a comprehensive overview of the components and applications likely to be involved in IoT, see Vermesan & Friess 2013.
[92] The many shifting coalitions for the internet of things (IoT) include AllSeen Alliance/AllJoyn, Open Interconnect Consortium/IoTivity, Industrial Internet Consortium, ITU-T SG20, IEEE P2413, Apple HomeKit. https://techbeacon.com/state-iot-standards-stand-big-shakeout
[93] IoT standardization projects at 3GPP are outlined in Reininger 2016. Also see http://www.itu.int/en/ITU-T/studygroups/2013-2016/20/Pages/default.aspx
[94] Hawkins 1999.
[95] ITU 2006; Blind & Gauch 2008; Hazucha 2013.
[96] Ahonen 2014.

communications technology and standards.

6.3 Factors affecting success of standards today

A number of factors will continue to affect the commercial success or failure of a given standard. Many formally adopted standards have never achieved significant commercial success. Standards that are widely adopted by industry participants are much more likely to be successful than standards that fail to attract support. This is especially important when multiple suppliers of complementary products or services (e.g., makers of mobile handsets, makers of mobile base stations, mobile communications service providers, and governmental agencies that allocate radio spectrum to the new standard) need to be enlisted in support of the standard. Open standards (for which numerous industry participants are able to participate in setting the standard) are likely to be more successful than less-open or proprietary standards in attracting support, as openness makes it more likely that all interested parties' concerns have been considered in framing the standard. The ability to adapt standards consistently over time as technical and commercial conditions change is another consideration.

Price and performance of the standardized products and services will clearly continue to be an important factor in commercial success. One (but only one) of the factors affecting cost is the total royalties sought by holders of patents used in standards-compliant products. Potential implementers of the standard want some assurance that they will be able to obtain reasonably priced licenses to patented technology necessary to make standards-compliant products, which is why most SDOs have a policy requiring holders of such essential patented technology to make licenses available on "reasonable and non-discriminatory" (RAND) or "fair, reasonable, and non-discriminatory" (FRAND) licensing terms and conditions. At the same time, developers need the opportunity to share in the success of standards as an appropriate incentive for investment in further R&D. There should be a balance between the needs of developers and implementers. For proprietary standards, it is important to attract the participation and support of suppliers of complementary goods/services. In either case, standards supporters will need a clear understanding of what the future licensing behavior of SEP owners is likely to be.

This implies, among other things, that continuity and predictability of IP licensing policies is important. Changes in IP policies, for both SDO and proprietary standards, and their legal interpretations, will need to be considered carefully in the context of the complete technology development, product innovation, standardization, and implementation ecosystems, such as those illustrated in the case studies.

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