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*Full Length Research Paper*

# A literature review on technology road-mapping: A case of power-line communication

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**Technology road-mapping (TRM) has become an important issue and has received increasing interest from both academics industry and business sectors. TRM is a powerful and flexible tool widely used in industry. Its principle use is to provide support in the form of strategic management and long-term planning of products or services for future development. The main purpose of this paper is to provide an analytical-review update for the issue of TRM. A case study of power-line communication (PLC) is used by implementing a technology roadmap process based on a data analysis. The studied results indicate the projected PLC trend of Thailand to be in the two areas of technology and market developments. The former indicates smart technological innovations. The latter, however, is not fully developed because broadband power-line communication has an influence only on a specific market. This situation shows that PLC is still playing a role only in some areas, due to business complexity.**

**Key words:** Technology road-mapping, technology forecasting, literature review, technological innovation, power-line communication.

## INTRODUCTION

Currently, technology road-mapping (TRM) development is applied to several technological development plans, both in company and industry-level organizations (Groenveld, 1997) . The primary objective of TRM development concerns integration between business strategy and technology development (Kostoff and Schaller, 2001; Phaal et al., 2002), establishing a direction that is common to both business strategy and technology strategy, and the superiority of a more-efficient technological development for use by an organization. Moreover, TRM is aimed right at the future of technology planning and can be expected to serve as a tool of significant technology-development prediction, with a suitable reservation for the future. Thus, TRM functions as an extremely useful device for technology management and industrial policy planning with indications for reliable procedures in future technology planning, and may even be utilized to lead strategy policy and operation levels, as well. In addition, the TRM project provides a considerably useful tool for correction and allocation of time, and its uses extend even to priority management.

According to the literature review, TRM is integrated with various organizations and industries. Yet, this literature review does not consider TRM action on power-line communication (PLC). Rather, this paper presents a literature-review update of TRM and the limitations of especially TRM integration, and then builds TRM in a case study of PLC. In addition, the advantage of PLC is on cable-data communication through transmission lines, an outstanding feature allowing internet connection speeds up to 45 Mbps (27 Mbps downstream and 18 Mbps upstream) (Fink and Rho Jae, 2008). As compared with broadband internet service in Thailand, with speeds limited to 8 Mbps, these speeds are faster than the

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current broadband capability. The primary advantage of PLC is that it offers a developed technology integrated communication data with electric-cable of the low-voltage electricity system. Additionally, PLC is easily set up at low cost and shows potential as a tool for high-speed broadband internet connection to every outlet in each household. Private sector and the government have both shown a definite interest in this technology. Meanwhile, the national telecommunications commission (NTC) of Thailand allows the provision of these services.

The creative-procedure portion of the TRM conceptual thinking approach to be developed for PLC in Thailand subdivides into 2 sections: the PLC-related products and service-provider technology. Furthermore, the authors interrelate TRM design to services/capability planning, as this type offers a larger suitability for service-based enterprises which focus on the ways in which technology supports organizational capabilities. This study requires a 5-year period from 2010 to 2014, inclusively. The first section is to follow the development of emerging technologies responsible to the progressive of PLC technology-development tracking. In particular, it will approve technologies and PLC technology strategic planning, estimation or upgrading. This section determines the best way to create new PLC technology strategies to support emerging technologies, and the degree to which PLC technology ability development is needed in order to follow these new technologies. The second section emphasizes the PLC development that is related to products and service-provider technology. In addition, this section will follow the current progress of the involved products and technologies in their tracking, inspection and strategy development and, at the same time, study their marketing feedback in order to conform marketing adaptation and technology strategy to ongoing market trends.

Results from the TRM power-line communication case study, which analyzed the correspondence of PLC technology as it changed through time during the last 5 years, shows that the wireless-technology solution played a significant role during this last period. Meanwhile, the low-voltage distribution cable continues to be used in technology access. The summary indicates that the future challenge of PLC in Thailand includes technology and market developments. Also, the PLC technology involves some highly interesting innovations. The PLC, for instance, has an ability to support connection devices such as Home Control and Home PNA. Because of its ability to support connection devices of these types, the technology clearly offers several competitive advantages. Accordingly, the overall image of PLC technology lies in the highly interesting techno-innovations. The market, however, is not fully grown because broadband power-line communication (BPLC) has an influence only on a part of the market. This limitation in the market results from internet-provider marketing factors. PLC continues nonetheless to play a role in some areas because of the prevailing business complexity.

## LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

### Overview of TRM

Currently, this new technology development integrates technology road-mapping (TRM) together with technological considerations for enhancement of productivity and improvement of efficiency to meet business goals. A former Motorola chairman and advocate of science and technology roadmaps, Robert Galvin, remarked that technology road-mapping (in its beginning stages) had been utilized since the 1970's. "A roadmap," in Galvin's own words is "A road map is an extended look at the future of a chosen field of inquiry composed from the collective knowledge and imagination of the brightest drivers of the change in that filed" (Galvin, 1998). Among the various roadmap types are national technology roadmaps, (Diebold, 1995; Spencer and Seidel, 1995) particularly industrial technology roadmaps (Ning, 1995) and international technology roadmap (Schaller, 2001). These roadmap communication activities include a vehicle-communication methodology to advise certain designated roadmap participants. They also resolve any problems that may occur during the process of vehicle arrangement, such as durational set-up. These functions accomplish the essential purpose of these activities, and the focus of this paper is directed toward their successful execution.

### Usage of TRM

Of interest here are TRM usage specifications from various technology roadmap providers and experimenters. The directional technology roadmap, which was first introduced and demonstrated by (EIRMA, 1997; Koen, 1997), is shown in Figure 1, together with TRM usage specifications. In addition to the general roadmap, Figure 1 also shows a time-based chart, which includes a number of commercial and technological aspects. Together, they enable the development of products and technologies. Further, they even enable markets.

### *TRM: A technological parallelism*

As Figure 4 illustrates, technology road-mapping spatially delineates or maps out the various phases of product innovation along an optimal path from product concept to product distribution. TRM integrates the various aspects of technology, business and practical production toward an optimum quality and output level of the final product in

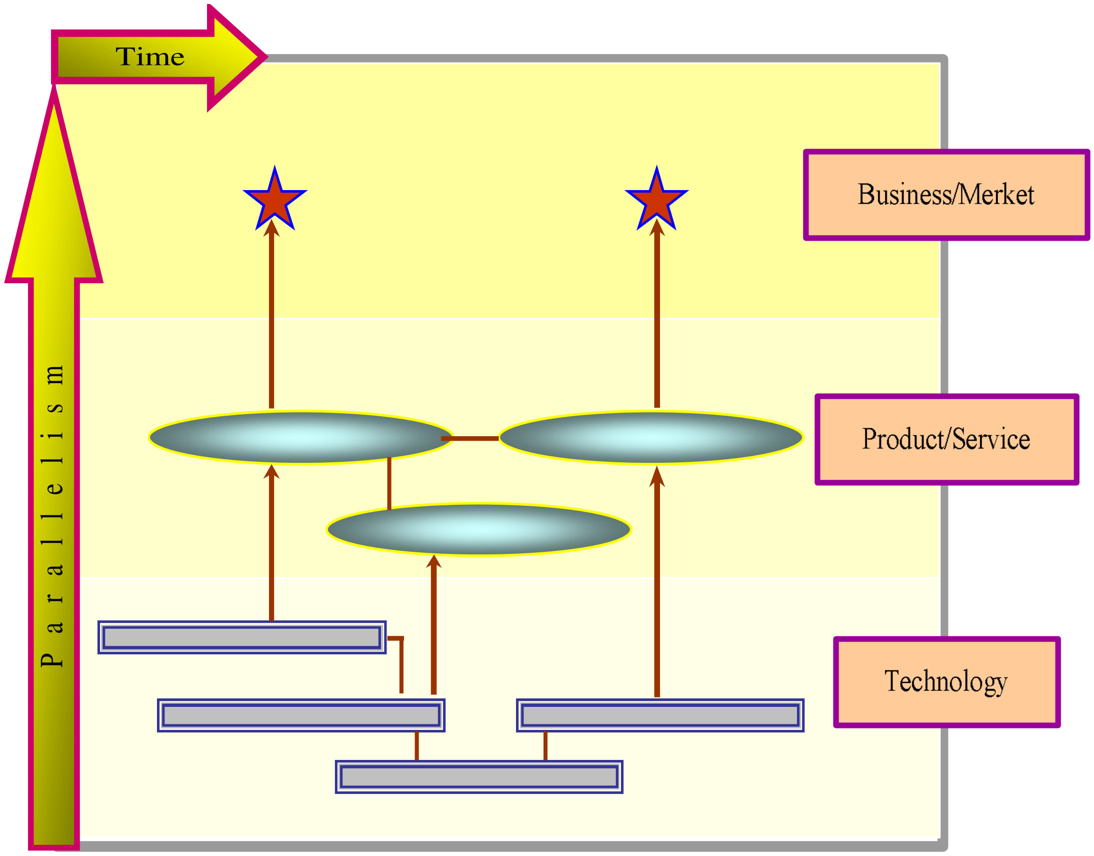



**Figure 1.** Technology roadmap: basic schematic.

the most cost-effective manner. Thus, technology road-mapping, as a technology parallelism, effectively does parallel the entire product-development process. Stated otherwise, TRM is itself a parallelism to the technology it assists. Accordingly, research and development aspects of the entire design process, together with the more prag-matic aspects of the production process, are optimized with respect to both the physical processes themselves and the relative timing of their activities.

### *TRM: methodology*

The method of road-mapping consists of time usage in connection with dimension gathering for a technology strategy structure. Once the overall characterization of technology roadmaps had been described, the structural pattern of exploring and communicating the relationships among markets, products and technologies evolved and developed into an easier implementing tool (Phaal et al., 2001, 2002, 2004). They showed that the road-mapping method was the primary factor in organiza-tional troubleshooting by means of organizational environment scanning, individual performance tracking and future-vision-oriented research integrated with various technological tools. Additional roadmaps tools were provided by Kostoff (2006), Lee and Park (2005). They provided a method of virtual innovation which they supported with (1) a roadmap technology especially suited to innovation factories, (2) knowledge of evolu-tionary technological patterns capable of incorporation with roadmap techno-logy for innovation and (3) market-limitation opportunities that discover and provide methods of self-organization simulation and possibility. Geisler (2002) likewise introduced an important compo-nent for technological estimation to assist an organization in its reach toward a future target. Eugenio et al., (2006) introduced an integration of strategic planning, roadmap technology and intelligent technology. Furthermore, Newman and Leverhantz (2001) introduced utilization of roadmaps for techno-logical identification and position. Also, Kappel (2001) Albright and Kappel (2003) and Groenveld (1997) added an additional focus on roadmap-technology integration with strategic planning tools.

Also, the energy sector is now using technology roadmaps. A review of the hydrogen-futures literature was provided by McDowall and Eames (2006), showing how utilized scenarios, roadmaps and similar foresight methods cope with uncertainty in areas with long planning horizons, such as energy policy. Moreover, research into the future prospects of hydrogen energy indicates that the trend will continue. Use of these methods leads to powerful expectations of emerging

### *Types of TRM*

The technological approach to road-mapping can be adopted in various ways according to the aims of the organizations and the sphere of graphical representation that roadmaps can represent. Product, innovation, business and strategic road mapping are terms that are applicable to a number of uses. One example is that of Phaal et al. (2001) who inspected a proximate grouping of 40 technology roadmaps extending into 16 broad areas (Figure 2(a) to 2(h)), as described in more detail in the following sections.

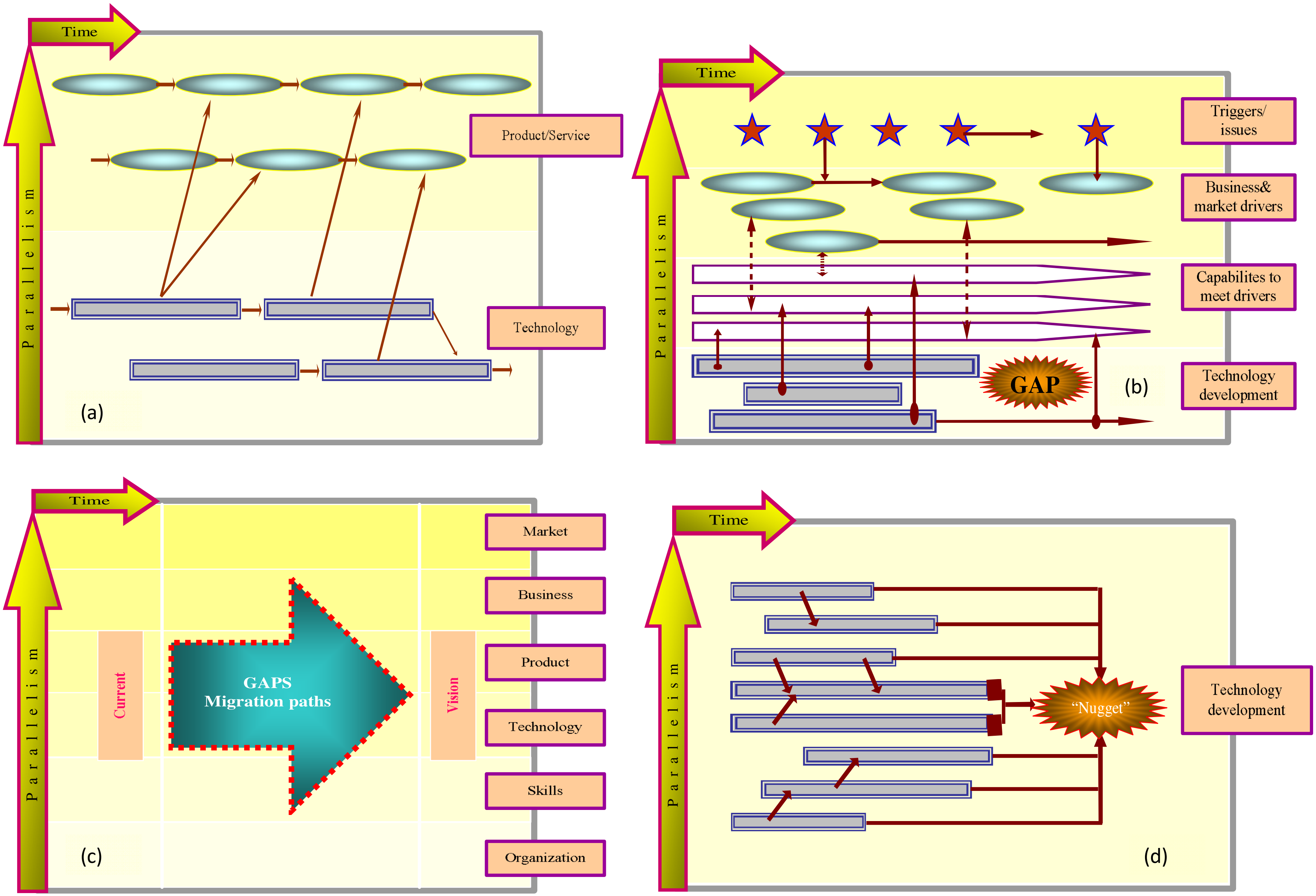
Moreover, in a 1998 TRM workshop, more than a dozen varying applications of roadmaps were presented. These groups observed structure and content to demonstrate intended purpose and graphical format. These are generally classifiable into four groups: 1) science and technology roadmaps, 2) corporate/product-technology roadmaps, 3) industry technology roadmaps and 4) product/portfolio management roadmaps. Each is classified, respectively, according to their applications and objectives (Albright and Schaller, 1998). Lastly, Kappel presents a road mapping taxonomy based on road-mapping purpose and roadmap emphasis.

As a result, a large number of roadmaps are subdivided into four groups. These are, namely, science technology roadmap, product technology roadmaps, industry roadmaps, and product roadmaps (Kappel, 2001). One can draw a taxonomic representation illustrating his objective. Kappel presents a road-mapping taxonomy based on concepts of road-mapping purpose and road-mapping emphasis. Some form of introduction can be deduced from this writing. For example, the clarification and reliability of roadmap types or categories can be sorted to appear feasible. Approximately at least a dozen different applications of roadmaps were presented at the technology roadmap workshop in 1998 (Foster, 1985). These applications cover a wide spectrum of usage, as in the following examples: potential techno-logies and the resources necessary for their realization, all of which combines to perform an important role in the development of a shared future vision. They used a six-fold typology to map out the state of scenario con-struction, expectations and exploration, and to provide for questions pertaining to the future of hydrogen. However, Bruckner et al. (2005) also provided an example of road-maps, exhibiting the distribution of energy technologies for public policy; and Hower (2004) provided a clean-coal technologies roadmap.

Technology roadmaps are also used in various areas, as in these examples. Yasemin and Ibahar (2007) successfully utilized roadmaps for technology integration in schools. Holmes and Ferrill (2007) and Ferrill (2006) applied techno-logy road-mapping to assist the Singaporean SMEs in emerging technology identification and selection. Walsh et al. (2005) extracted a semicon-ductor silicon industry roadmap which focused on epochs driven by the dynamics between disruptive technologies and core capabilities.

Kostoff et al. (2004), Linton (2004), Vojak and Chambers (2004), Galvin (2004) and Walsh (2004) promoted an awareness of road-mapping disruptive technologies. Walsh (2004) also studied into road-mapping as a disruptive technology and focused on the case study of the emerging micro-systems and top–down nano-systems industry. His study involved theoretical utility investigation and practice for traditional technology road-mapping tools in an international indus-trial road mapping effort. He focused firstly on micro-technology and top–down nanotechnology, and then on modifying the traditional technology road-mapping approaches to generating a model for an industrial worldwide disruptive-technology road-mapping process. Fleischer et al. (2005) likewise investigated the emerging technologies estimation, focusing on nanotechnologies. Roadmaps are effectively used in product development and a group of studies were focused in this area. Petrick and Echols (2004) investigated technology road-mapping for decision improvement in new-product development. Bray and Garcia (1997) similarly focused on strategic and technology planning integration for compe-titiveness. However, Bucher and Jung (2001) also provided an implementation from Asea Brown Boveri (ABB) Limited and Passey et al. 2006), who studied the procedure of integration in product-concept vision and scenario structure with roadmaps. Lee et al (2006), Sungjoo et al. (2006) utilized patent information for new product development by a keyword-based technology road-mapping approach. Yasunaga and Yoon (2004) studied utilization of technology road-mapping with knowledge structure in R&D management.

1. Science or research roadmaps, e.g., science mapping;
2. Crossed-industry roadmaps, e.g., the Industry Canada initiative;
3. Industry roadmaps, e.g., the SIA's International Technology Roadmap for Semiconductors;
4. Technology roadmaps applicable to aerospace, aluminum and other such areas;
5. Product roadmaps like those of Motorola and Intel, among others;
6. Product–technology roadmaps like Lucent Technologies and Philips International;
7. Project/issue roadmaps such as are used for project administration.


Time
Parallelism
Product/Service
Technology
(a)
Time
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Triggers/ issues
Business& market drivers
Capabilites to meet drivers
GAP
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Time
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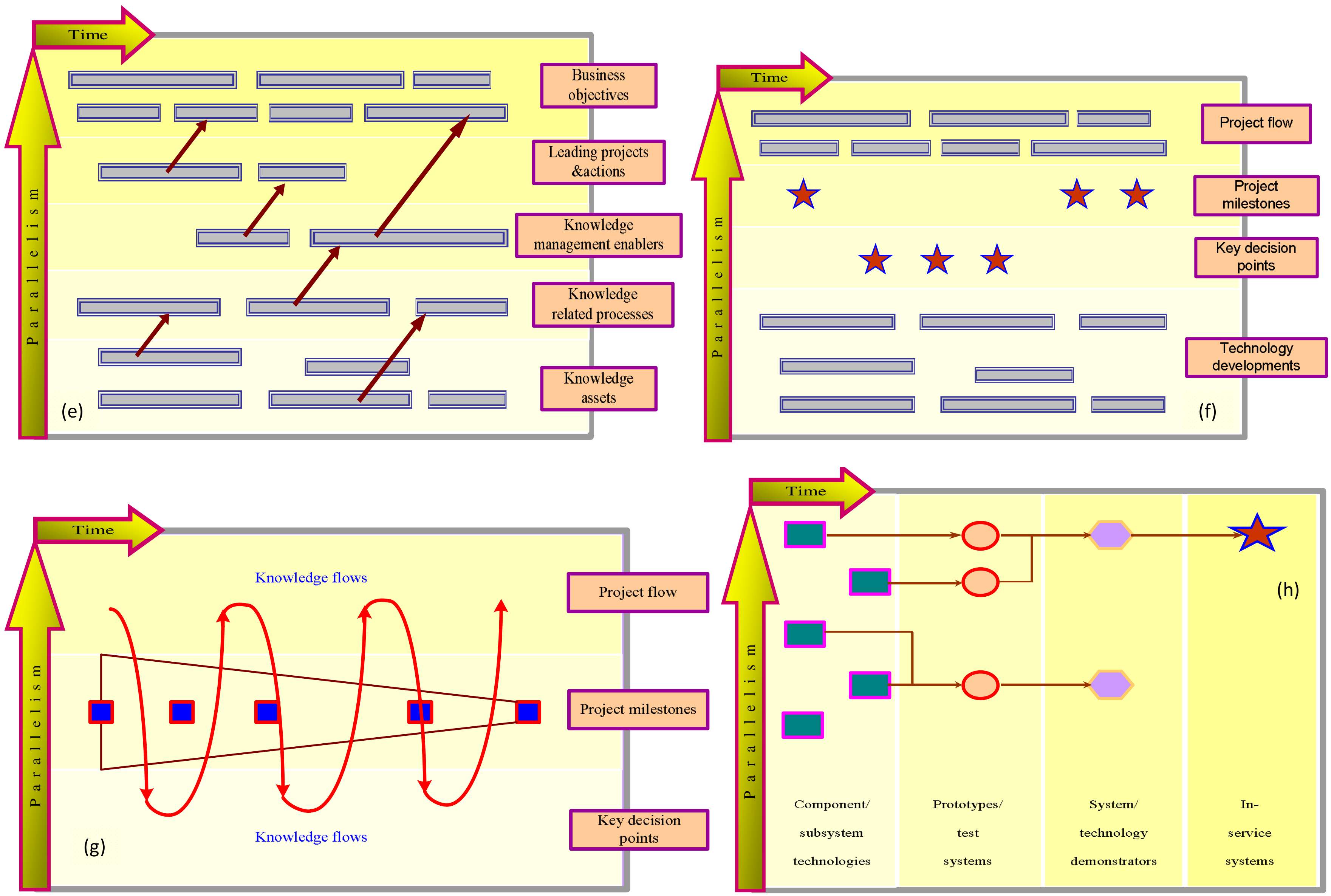


**Figure 2(a).** Technology roadmaps: basic types and applications( a)(Product planning). (b) Service/ Capability planning. (c) Strategic planning.(d) Long range planning. (e) Knowledge asset planning (f) Program planning (g) Process planning. (h) Integration planning.

From this diversity of usage, a taxonomy is proposed in an attempt to classify roadmaps for the visualization of their locations in applications.

### *TRM software use*

Software has an important role to perform in enterprise road-mapping application support (Duckles and Coyle, 2002), as does, for instance, the Vision Strategist software for strategic-planning collaboration. Vision Strategist™ is the first and only centralized product-planning software for business-development plans and objectives across the enterprise. It offers an uncommon solution allowing organizational users to automate the strategic-planning process and to visualize alternatives selection for breakthrough product opportunities Additionally, Vision Strategist™ directly assists the perceptions of decision-makers regarding their company's future direction by the use of roadmaps, which are time-based information representations that support a specification objective or decision process. The advantages of TRM software consist mostly of the following features:

1. Increase in new revenue by revitalizing innovation and identifying new opportunities;
2. Cost reduction by maximizing reuse and reducing redundant technology development;
3. Better alignment and synchronization across functions and organizations;
4. Improvement of an organization’s agility by creating a strategic plan that reacts to market changes in real time;
5. Accountability and ownership in maintaining each individual's role in the overall strategy and communication of those responsibilities to others;
6. Expansion to meet a diversity of additional necessary components with suitability of corresponding applications and modules.

Nevertheless, software alone cannot deliver good roadmaps. It must, instead, be integrated with the human aspects of road-mapping, as well. Accordingly, a main benefit of TRM will lie in the expansion of knowledge and the furthering of a shared vision of the company’s future. This benefit will materialize only in the sharing of knowledge and making connections.

### *Benefits of TRM*

A principal key advantage of the process is the organization-wide communication support that takes place during the development and expansion of the road-map. This method is especially effective for synthesizing varying perspectives, deriving, as one case in point, a balance of commercial and technological functions. In addition, road-mapping is also able to support the following activities:

1. Expediting the new resource integration such as novel technologies;
2. Identifying potential opportunities and threats;
3. Supporting high-level planning and control;
4. Emphasizing understanding or close knowledge gaps;
5. Providing support for decision making, resource allocation and risk management.

## A CASE STUDY OF POWER-LINE COMMUNICATION (PLC)

### Background of PLC technology

Power-line communication (PLC) (Jee et al., 2003; Weilin et al., 2003) is a technology enabling utility companies to deploy a communications network over existing power-line infrastructures by the transmission of data signals through the same power cables that transmit electricity. Besides, all types of home cable, whether low-voltage (110-220 volts) or medium-voltage (1,000-40,000 volts) distribution cable, function as PLC. Power-line communication is occasionally referenced by different names like, for example, broadband over power line (BPL) and power-line telecommunications (PLT). Moreover, many sources tend to describe and detail it in different terms. In this paper, this technological concept will be designated as power-line communication (PLC). PLC is a technology employing an electrical supply network to support data transfer and includes both the narrowband PLC and electric-power control in a public utility. Narrowband PLC, for example, extends to electrical equipment control and home security, while electric-power control may apply to power-supply activation through a switchgear process control, automation meter reading (AMR) and tariff broadcast. The power utility provider starts to develop this technology by using high-voltage distribution line communication and controls between substations. Currently, it is capable of high-speed data transfer (broadband PLC), such as high-speed internet, video streaming and VoIP, through low-voltage distribution cables. For this reason, its development can proceed over an access network, instead of a telephone line.

Power-line communication began shortly after electrical power supply became widespread. Carrier frequency systems began to operate over high-tension lines in frequency levels of 15 to 500 kHz for telemetric objectives and continued operation from approximately the year 1922. Various consumer products, such as baby-alarm systems, have been available for dedicated consumer usage at least since 1940 (Dostert, 1997). In addition, from the 1930s (Broadridge, 1984), ripple-carrier signaling became accessible in the level of low-voltage

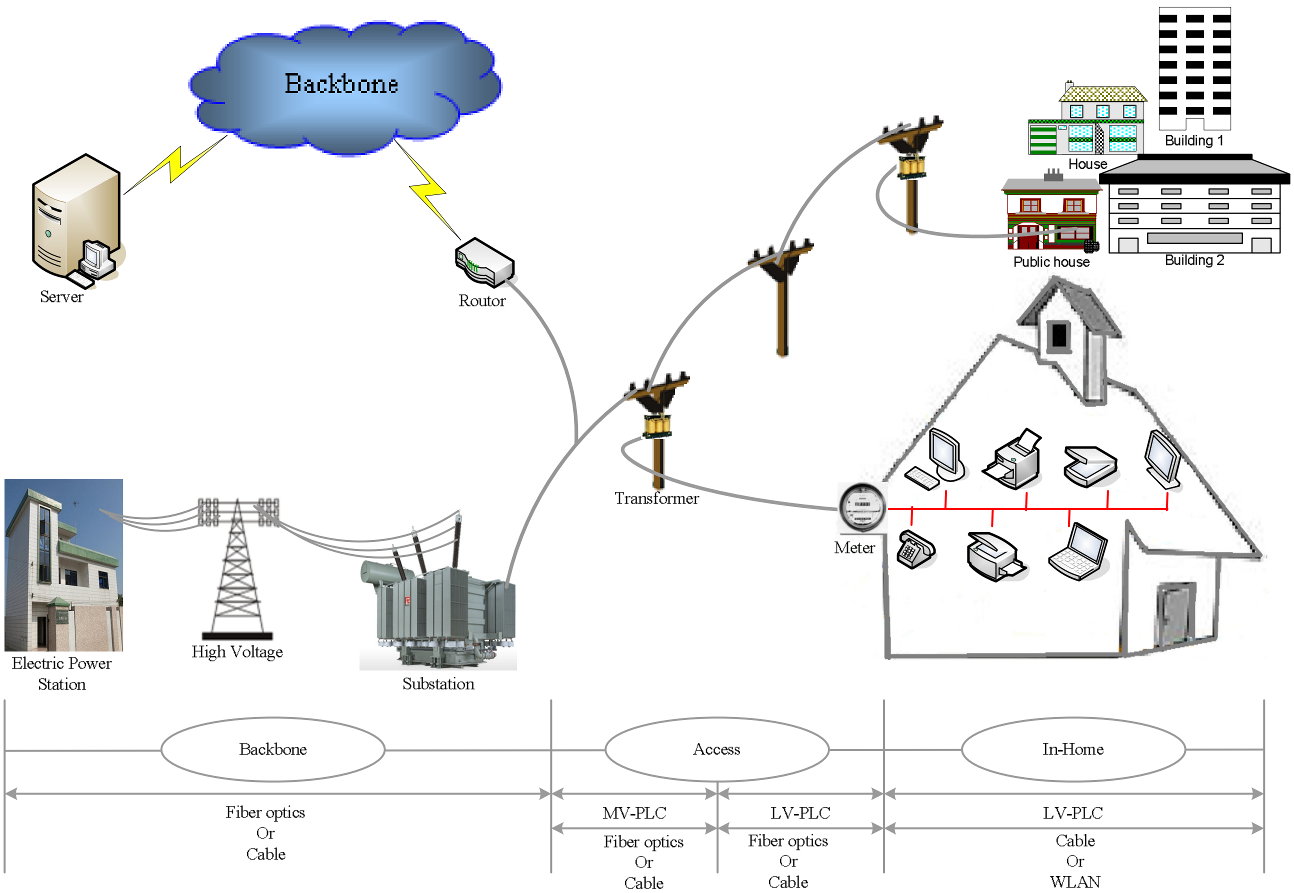


**Figure 3.** A power-line communication (PLC) network: general flow diagram.

(240/415V) and medium-voltage (10 to 20 KV) distribution systems. The challenge of this operation lies in the field of bi-directional technology. For example, Tokyo Electric Power Co., the largest of Tokyo's electric-power companies, began its experiments in the 1970's and eventually reported success in many hundreds of units after experimentation ended. From mid-1980 (Hosono et al., 1982), interest grew in the potential value of digital-signal processing. Communication usage techniques have since increased with the application of concepts that can be implemented at low cost. These concepts have been applied to the production of systems which are capable of being widely installed, allowing them to compete well with wireless solutions. However, the communications channel of the narrowband power line presents numerous technical challenges.

There are 4 main supplies of systems to PLC networks, namely: 1) devices utilizing DS2 chip sets, 2) devices utilizing Intellon chip sets, 3) devices utilizing Xeline chip sets and 4) devices utilizing Panasonic chip sets. Most recently, because PLC devices use different chipsets, they have been unable to communicate with each other in PLC networks, though steps are now being taken to standardize the process by chip venders and project groups. The creation of a "Draft Standard for Broadband over Power Line Networks: Medium-Access Control and Physical-Layer Specifications" by the IEEE P1901 working group (IEEE P, 1901) attempts to do so. Medium voltage (MV) PLC and low voltage (LV) PLC are divisible by PLC as shown in Figure 3. The MV PLC uses a 22.9 kV power line between the substation and the transformer, while the LV PLC uses a 110V / 220V power line in common with the transformer and household power line. The PLC network comprises various PLC devices, among which are master modems, slave modem, repeater modem and MV/LV gateway (Lee et al., 2006). A specified device is used to connect network backbone, like the fiber network, xDSL, as well as a cable network to the PLC network through a master modem. In addition, a repeater modem is a device used to signal amplification between various PLC devices, and a slave modem is a device used for signal-transfer between PLC network and home devices like the PC. A MV/LV gateway mediates between MV, PLC and LV PLC. However, the PLC networks remain under management by the PLC Operation Center by way of the internet connection.

## Business of PLC

The PLC requires comparatively less expense than an internet network, since the transmission system requires a smaller investment. Because of its low expense, PLC technology is becoming popular. In general, the business plan always estimates the capital in PLC system planning below the actual required outlay. The PLC system should be of a fit design, so that, at the beginning of the plan, the expert designer may come to a reliable expense evaluation for the system in its current design state. Ultimately, the people who succeed in the PLC business will not be the public-utility service supporters, but the telecommunication planners and those who operate the internet services.

Consequently, the cost of installing all the equipment in homes and in buildings, designated here as customer promise equipment (CPE), is a critical factor in the PLC business. However, the CPE cost is continually and incrementally decreasing and will soon reach the point at which it will compete with other technologies, such as DSL or Wi-Fi Access Point.

## Design-technology road-mapping of PLC

The creative-procedure portion of the TRM conceptual thinking approach to be developed for PLC in Thailand subdivides into 2 sections: the PLC-related products and service-provider technology. Furthermore, the authors interrelate TRM design to services/capability planning, as this type offers a larger suitability for service-based enterprises which focus on the ways in which technology supports organizational capabilities. This study requires a 5-year period from 2010 to 2014, inclusively. Figure 2(b) shows a Royal Mail roadmap, based on an initial T-Plan application (Brown and Phaal, 2001), used to investigate the impact of technology developments on business. This roadmap focuses on organizational capabilities as the bridge between products and service-provider technology. Consideration of these factors over the 5-year period from 2010 to 2014 will involve the following points:

1. The first section is to follow the development of emerging technologies responsible for the furthering of progress in PLC technology-development tracking. In particular, it will approve technologies and PLC strategic planning, estimation or upgrading. This section determines the best way to create new PLC technology strategies to support newly emerging technologies, and the degree to which the ability development within the PLC is going to be needed in order to follow these new technologies.
2. The second section emphasizes the PLC development that is related to products and service-provider technology. In addition, this section will follow the current progress of the involved products and technologies in their tracking, inspection and strategy development and, at the same time, study their marketing feedback in order to adapt and conform marketing and technology strategy to current and projected trends.

Through the TRM conceptual thinking approach, PLC can be related to products and service-provider technology. From the results derived from consideration of the TRM of power-line communication case study, the authors have created a TRM of PLC at different points in time during the previous 5 years. They have analyzed the patterns of PLC technology change during the period 2010 to 2014 and divided the TRM structure into 4 main factors. These factors comprise access, product, technology and time, and are related to each other in the manner shown in Figure 4.

The power-line communication (PLC) technology has evolved from the narrowband offerings into a broadband pipe known as broadband power-line communication (BPLC). BPLC has two primary applications: broadband access (BPLC-Access) and home networking (BPLC-Indoor). The TRM of the power-line communication case study served to analyze patterns of PLC technology change at various times during the 5-year period under consideration. From Figure 4, the results derived from consideration of the case study shows that the wireless-technology solution had a role during that last period, and that the low-voltage distribution cable continues to be used in technology access. A summary indication of the PLC trend for Thailand's future reveals 2 aspects. These are the technology and market developments, as shown below:

**Technology:** PLC technology has a highly interesting role to play in deriving solutions for the development of access technologies. Moreover, PLC technology has the capacity to support connecting devices like Home Control, Home Networking, Utility Application, Wire Broadband and Internet Access. Also, BPLC-Access offers higher data rates than other widely-available competing alternatives, such as DSL and cable modem. Similarly, BPLC-Indoor competes well against other home networking technologies, such as Wi-Fi and HomePNA, and offers several competitive advantages, as well. Consequently, PLC technology in its overall image offers, as an added advantage, several competitive advantages and stands clearly as one of the most highly interesting of techno-innovations;

**Market developments:** As Jeong et al. (2008) show, BPLC can be expected to occupy only a small portion of

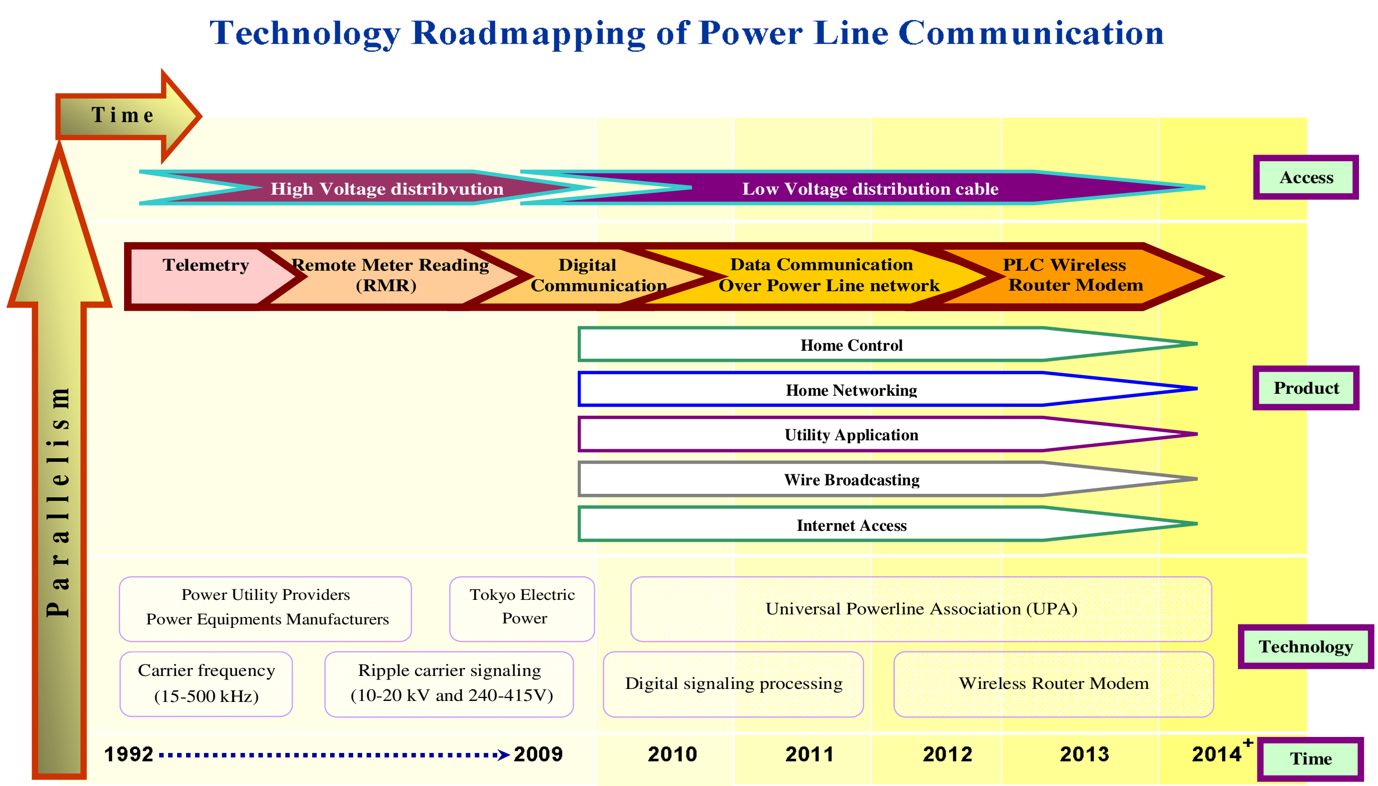


**Figure 4.** Technology road-mapping may be utilized for the digital capture of their development to maximize production efficiency.

Korea's internet-access market in the future because of internet-provider marketing factors. Their report details global BPLC deployments, examines emerging BPLC devices, discusses standards and regulation and profiles major vendors marketing BPLC equipment. Their report also examines developments in BPLC technologies, compares these technologies with other competing solutions and provides market sizing and market forecasts for both BPLC-Access and BPLC-Indoor. The report indicates that PLC cannot be dominant in all areas in a competitive market because of the complexity of modern business. Hence, the PLC market is in need of further growth.

## DISCUSSION

Experimentation in the area of technology road-mapping is primarily directed toward the use of TRM as a practical technology-planning tool within an increasingly competitive environment, as in the application of TRM to the approximation operation (Gerdsri et al., 2008) of SCG Building Materials Co., Ltd. This utility results from the practical support of technology road-mapping for multiple technologies and development coordination of multiple projects. This coordination is critical when treating the issue of technologies that are related to the core capabilities of an organization. Nonetheless, careful consideration of alternative technologies and organizational necessity will be of greater importance than merely following a precise process format. The result of this study points to the successful appropriation of a technology road-mapping process that will, in time, be of value. This technology, however, still needs to be corroborated by a reputable organization and cannot be guaranteed as valid except by verifiably reproducible results.

In this paper, the authors have presented an overview of technology road-mapping, lending particular attention to the case study of TRM of PLC, in which they analyze the pattern of PLC technology change over time. As discussed above, a 5-year period is required for the case-study analysis. Further, the PLC trend for the future can be viewed from 2 aspects. The first aspect is technology. PLC technology is remarkably interesting to follow in its development as an access-technology solution. PLC is also capable, in addition, of supporting the connected device and satisfying multi-function requirements. The PLC technology is, accordingly, among the most interesting of techno-innovations. The other aspect lies in market developments. According to the current data, BPLC has an influence only on a part of the market because of internet-provider marketing factors. This situation forces the realization that PLC is still playing only a limited role in some areas because of business complexity. The PLC market is, therefore, less than fully grown.

Work is expected to continue on technology road-mapping of PLC. Likewise, research on the similar communication technologies will continue with comparisons of the progress being made in each of the technologies. In general, effective use can be made of a software tool like Geneva Vision Strategist or any other such tool for designing technology road-mapping. As work continues, future reports will provide updates on its progress by using these tools in creating technology road-mapping, which, while fairly simple in design, saves time in development. This methodology differentiates the technology and very vividly highlights comparative strengths that exist within the technology.

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