Next Generation Networks: Whence, Where, and Whither

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ABSTRACT

The last decade witnessed many Next Generation Networks (NGN) with each having a short life of only few years. The Second-Generation Network (2G), which is already out of vogue in most advanced countries, is still being deployed in third world countries. The Third-Generation (3G) Network was expected to solve all the problems encountered in the previous generations, but the persistent demand for higher rates and the non-compatibility of the 3G standards has shifted the enthusiasm to Beyond 3G (B3G) or Fourth-Generation (4G). This paper re-examines the various generations of network standards with the intention to focus the mindset of the telecom planers and designers and also raise their research consciousness.

(Keywords: second generation, 2G, third generation, 3G, fourth generation, 4G, beyond 3G, B3G, communication networks)

INTRODUCTION

The Next Generation Networks (NGN) have become an unending phenomenon; a phrase whose real meaning has a life-span of only few years. This is, in part, due to the unprecedented innovations in telecom technologies. On the other hand, the phrase could not have a stable meaning because each generation of standards has unfortunately, so far, failed to accomplish its proclaimed objectives. In third world countries, network operators are still struggling to deploy 2G when it is already out of vogue in most advanced countries; even before it is first deployed in developing countries. This paper not only builds on earlier papers [1, 2, 3, 4], but it is expected to focus the mindset of telecom planers and designers in the third world to be proactive and not always play catch-up with technological standards.

Modern telecommunications networks began with the First-Generation Networks (1G), which were built to support analogue mobile phones in 1984. The 1G networks were, more or less, a proprietary standard, with almost every nation or region having its own standard. Moreover, the network could only support voice traffic, with very poor quality.

In 1980, the European Union's (EU) need for roaming among member countries and for a relatively reliable digital mobile phone network led to the development of the first Second-Generation network standards - Global System for Mobile (GSM) network. The GSM network is based on Time Division multiple Access (TDMA) Air Interface technology. A variation of the TDMA mobile technology (IS136) was later adopted in the USA by AT&T and some other operators as PCS.

The dominant 2G standard in the USA that followed after the GSM is the Code-Division Multiple Access (CDMA), which was introduced in 1992. The 2G technologies were optimized for voice. At about the same time, the Internet was becoming popular and the ability to move data between computers and networks was beginning to become routine. As a result, the text messages and the low bit rates, which the 2G networks could only support, proved very inadequate. While the older generation of mobile users began to demand the ability to be able to transfer relatively large data and images, the teenage market segment expressed the consumer need for music and video clips, video streaming, etc. which are also capacity intensive. Coupled with this was also the fact that many mobile operators were facing unprecedented turnovers and were, as a result, searching for a new service differentiation to maintain their revenue. These expectations from customers and the desire to maintain revenue on the part of the operators led to approval of Third-Generation (3G) wireless networks standards by the ITU in 1999.

The 3G standard was touted as a panacea for all of the customer expectations that could not be met in 2G. In terms of speed, the theoretical data rate that GSM mobile networks could support is 9.6 Kbps, while the CDMA networks could support up to 14.4 Kbps. The standard [5] that the ITU approved was called International Mobile

Telecommunications-2000 (IMT-2000), and the following bandwidth were specified:

- 144 Kbps or higher for higher mobility traffic
- 384 Kbps for pedestrian traffic and
- 2 Mbps for Indoor or in-building traffic.

The life-span of each of the generations of wireless network has proven to be too short and increased the difficult for operators to carry out full-blown migration to next generation technologies. The operators are in business to make profit and desire to protect prior investments. The need to recoup their investments meant that operators prefer a step-wise or phased migration and so rather than moving to 3G, they first migrated to 2.5G and then to 3G. Although there are many operators that have been offering 3G since 2002, enthusiasm for 3G is waning. This is primarily due to the data rates observed from the 3G networks.

The two main evolution standards for 3G are W-CDMA (wideband CDMA) and variations of CDMA2000, with CDMA2000 1x EV-DO (evolution data optimized) expected to offer higher rates. Tried-and-tested [6] 3G technologies of CDMA 2000 1x EV-DO cannot maintain a 1Mbps speed on average and the looming alternative of W-CDMA promises an average throughput of around 1~2 Mbps.

Furthermore, Third-Generation (3G) services have proven so disappointing, because instead of one worldwide standard, there are three incompatible systems in the United States alone [7]. The demand for higher rates and the non-compatibility of the 3G standards has shifted the enthusiasm to Fourth-Generation (4G) wireless networks.

When 4G technologies finally go to market, they will support rates above 100 Mbps [8]. They are also expected to integrate all wireless networks, and be application independent. Particularly, 4G will support location-based services, mobile shopping, e-mail and multimedia data transfer, video conferencing, video streaming, etc.

This paper is therefore intended to retrace the various generations of wireless network. It will examine each generation and take comparative studies of each in relation to subsequent generations. Broadly, the discussion will cover 1G, 2G, 2.5G, 3G, and 4G. The 4G visions will be examined in details.

A REVIEW OF STANDARD BODIES

Figure 1 shows the major organizations responsible for wireless standards. We describe briefly some of these standards bodies, but a detailed description would be devoted to others when we discuss 3G proposals later.

- The ESPIRIT is the EU Strategic Program For IT. It is an EU funded R&D projects to facilitate the success of EU industries relative to timely adoption of IT products and services.

- The Telecom Industries Association (TIA) is an association of companies that sets standards for computer and Telecom technologies in the US. Notable standards are TIA-41, 95 and 136.

- The Institute of Electrical and Electronic Engineers (IEEE) is an association of Electrical engineers, the largest in the world. It is responsible for the 803 series standards.

- The International Telecommunications Union (ITU) is a UN agency. It is the father umbrella of all the international standards in Telecommunications. It is divided into sectors to address specific area of telecomm.

- The EU conference of Post and Telecomm (CEPT) is EU funded and its objective is primarily to harmonize telecom regulations in EU.

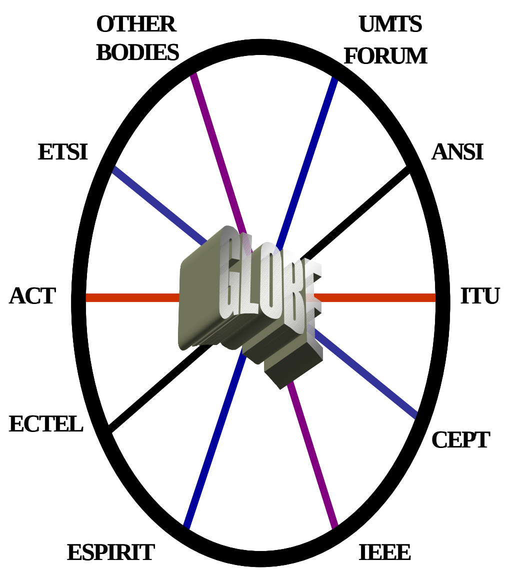

Figure 1: Some Wireless Standards Bodies.

WHERE AND WHENCE THE NGN

Advances in digital and communications technologies have created an insatiable desire for access to high bandwidth applications; any-where and any-time. This desire has led to rapid developments and hitherto the ephemeral nature of subsequent generations of wireless network in the last decade. It is said that the mobile radio system [8], which is a prelude to current mobile networks, went into operation as far back as April 7, 1928. It was also said that the first successful system was used by the Detroit Police Department. The system used Amplitude Modulation (AM) and as a result suffers from spike noise, which is prevalent in electromagnetic oriented systems. However, in 1935, Frequency modulation (FM), which proved to be more resistant to the noise problems in AM was developed and tested by Mr. Edmond H Armstrong. Aside from the noise problems, another major issue at the time was the large carrier bandwidth required. In order to transmit a voice grade signal of 3KHz, a spectrum of 120KHz was required. However, the development of the FM can achieve this feat with 30KHz, which is about 400% efficiency achieved by FM over AM.

World War II was also a major catalyst for the developments that led to mobile communications. During war time, the FM based mobile radio was the main thrust of communications. Shortly after the war, AT&T developed what was called the Improved Mobile Telephone Service (IMTS). Primarily, the system was introduced to cater to a metropolitan area and consists of a broadcast system and a high-powered transmitter. IMTS evolved into a limited cellular system and was integrated with the fixed telephone system in the 1950s. Subsequently, this led to the development of paging systems that took advantage of this technology. Bell Labs, the innovative arm of AT&T at the time, continued its cellular research and testing and in 1970 they were successful in convincing the Federal Communications Commission (FCC) to allocate spectrum space to cellular systems.

The allocation of cellular frequency gave AT&T the impetus to propose the very first, First-Generation (1G) network known as the Advanced Mobile Phone System (AMPS), which was implemented in 1983 in the US. This was followed by the Total Access Communications System (TACS) implemented in the UK in the 900MHz frequency range. TACS is an offshoot of AMPS. In Japan a variation of TACS, JTAC was deployed in the 800 and 900 MHz range.

At the same time the 1G Analog Cellular systems in Sweden, Norway, Denmark, and Finland were being deployed as the Nordic Mobile Telephone (NMT) systems in the 450 and 900 MHz range. Germany was the main user of the 450 MHz. AMPS was the 1G system widely used in the North America.

In the EU, the story was a bit different; because of the different systems that existed in the different countries, mobility and roaming beyond those system areas were major problems. The problems were of major concerns to EU member states when the 1G was being deployed and research into a unifying digital system was commissioned. This unifying 2G systems were surnamed Global System for Mobile Communications (GSM). Thus, GSM, the first 2G system was deployed in 1991. The US was not in haste to evolve their 1G to 2G because the single AMPS standards adopted provided reasonable mobility and roaming among over forty countries. It was not until 2 years after the deployment of GSM that US firms and other countries began to deploy 2G. In Table 1, we observe that there are four common types of 2G air Interfaces. The GSM uses a variation of Time Division Multiple Access (TDMA) air interface technology. The Personal Digital Cellular (PDC) was the 2G system deployed in Japan.

In the US there are three 2G mobile standards: TIA/EIA IS-95, IS-41 and IS-136. The TIA/EIA is the US Telecommunications Industry Association and Electronic Industry Association, which has now become TIA. The Interim Standard (IS-136) defines a 2G TDMA mobile technology and Digital Control Channel (DCCH) for use in the US. It supersedes IS-54, which defines dual mode – analogue and digital standard for cellular phone service. The IS-136 enabled TDMA and AMPS to coexist in the network and share the same resources. Thus allowing 1G AMPS to gracefully evolve to 2G TDMA. On the other hand, the IS-95 is a 2G digital Code Division Multiple Access (CDMA) standard for use in the US and South Korea. It is a Direct Sequence Spread Spectrum (DSSS) patented by Qualcomm Inc. In other words, any company using CDMA or a variation thereof pays royalty to Qualcomm. In June 3, 1997, CDMA Development Group (CDG) named the 2G CDMA as CDMAOne. The Personal Digital Cellular (PDC) system is the 2G deployed in Japan.

There are other 2G systems around the world, but these are predominantly variations of GSM or of CDMA. A simple discussion on GSM and CDMA is given in [17].

Table 1: Comparing Wireless Generations.

Generation	1G	2G	2.5G	3G	4G
Design Begin	1970	1980	1999	1990	2000
Implemented	1983	1991	1990	2003	2010?
Standards	AMPS, TACS NMT, etc.	TDMA, GSM CDMA,PDC	GPRS, EDGE 1xRTT, IS-95B	WCDMA,UWC CDMA2000	One Standard
Services	Analogue Voice	Digital Voice Messages	High Capacity Packet Data	High Capacity Broadband	Complete IP Multimedia
Multiplexing	FDM	TDMA,CDMA	TDMA,CDMA	CDMA	OFDM
Core Network	PSTN Circuit	PSTN Circuit	PSTN Packet	Packet	Internet
Modulation	FDM	GMSK	8-PSK	Walsh	???
Data Rates	>9.6 Kbps	>14.4 Kbps	>384 Kbps	>2 Mbps	>200 Mbps

The theoretical data rates are given in the Table 1. The 1G could move data up to 9.6 Kbps using V.32 modem, which was the highest rate at the time of the deployment of AMPS in the early 1980s. Table 2 gives ITU defined voice modem standards and associated data rates. The 2G technologies do not need a modem to convert analogue to digital as in the case of 1G, and as such, could not benefit from modem enhancement years later. The coding scheme of the 2G base stations can only allow 9.6 Kbps for GSM/TDMA and 14.4Kbps for CDMA technologies. In the 1980s, computer users of Local Area Networks (LANs) had been used to moving large data and documents from one computer to another, so rates less than 14.4 Kbps had become too insignificant and so while developments were still ongoing for 2G, work began on 2G enhancements (2.5G) in about the middle of 1980s.

Table 2: Voice Modem Standards.

Standard	Year	Data Rates (Kbps)
V.22	1980	0.6 or 1.2
V.22 bis	1984	1.2 or 2.4
V.32	1984	4.8 or 9.6
V.32 bis	1991	V.32, 9.6, 12 or 14.4
V.34	1994	Up to 28.8
V.90	1997	Up to 56

The 2.5G General Packet Radio Service (GPRS) and Enhanced Data for GSM Evolution (EDGE) are enhancements to 2G GSM. Similarly, IS-95B and CDMA2000 (IS-95C) are enhancements to CDMAOne.

GPRS was deployed in 1999 to support GSM rates up to 144 Kbps, while EDGE could support rates up to 384 Kbps. IS-95B was designed to deliver 64Kbps initially, but ultimately - 115 Kbps in 2.5G, whereas IS-95C is 3G. In the Figure 2, we have compiled the evolution path for 2G through 3G and beyond.

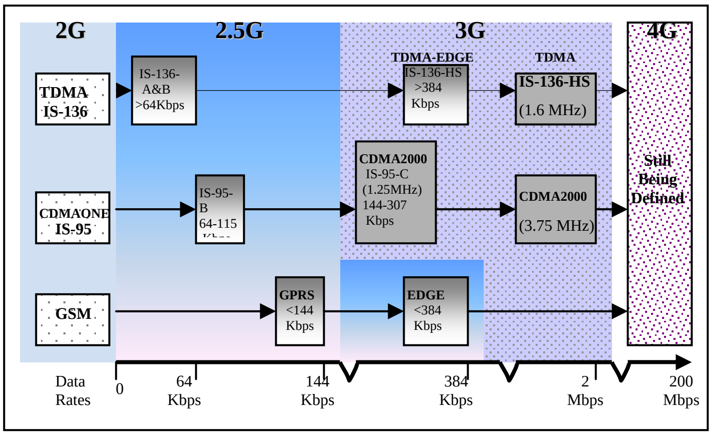

Figure 2: Evolution Path for Wireless Standards.

As we have already seen, the 2G has very low bit rates and therefore cannot support applications demanding very high bit rates. Though the enhancements to 2G could offer rates beyond 144 Kbps, other short falls militated against these enhancements. We have also seen that there were many frequency ranges allotted by different countries in the range of 450, 800, 900, 1800, 1900 MHz for 2G, making roaming between different networks complicated and limiting.

Most of the 2G infrastructures are proprietary in nature, but infrastructure development trends are now toward open system architectures that support third party applications development.

Another major factor militating against the 2G was technological development in the core of the network and optical domains. In the 1980s, switches and routers could only switch E1/T1 and E3/T3 rates, but in the 1990s, routers and switches capable of Giga Hertz capability became commonplace. Dense Wavelength Division Multiplexing (DWDM) that could switch in the Terabit per seconds (Tbps) was also developed in the last decade. These technological developments influenced new thinking among designers and thus new services development that 2G could not support seamlessly.

These observed shortfalls in the 1990s led to a demand for a new generation (3G) of mobile technology for the new millennium. These demands were given effects by ITU-R in conjunction with other national standards organizations in different countries and continents around the world. The ITU set up an initiative to coordinate the defining of the specifications and standards for 3G. The initiative [5] was named International Mobile Telecommunications for the 21st Century (IMT-2000).

In the EU, the Telecommunications Standards Institute (ETSI), a research and development projects funded by EU, set up Special Mobile Group (SMG2) [18] to define and submit specifications that would evolve GSM. W-CDMA and TD-CDMA were proposed to ETSI in January 1998. In Japan, the Association of Radio Industries and Business (ARIB) submitted a W-CDMA proposal, and also a CDMA2000 proposal, to evolve their 2G systems. China Wireless Telecommunications Standards (CWTS) also proposed a variation of the W-CDMA (TDSCDMA) in 1998 and became a member of 3GPP in 2001. The Telecommunications Technology Association (TTA) of Korea proposed W-CDMA and CDMA2000 versions to evolve its TDMA and CDMA 2G technologies to 3G. In North America, four proposals were submitted:

1) A CDMA2000 proposal (TIA-45-5) submitted via the efforts of Samsung Motorola, Lucent, Nortel, and Qualcomm

2) A TDMA (UWC-136) evolution proposal (TIA-45.3) by AT&T, South Western Bell and BellSouth

3) A WIM evolution proposal (TIA-46.1) by Golden Bridge Technologies and

4) A W-CDMA evolution proposal (ATIS TIP1) for GSM Networks.

The foregoing discussions show that many 3G proposals were submitted to ITU. Indeed, in response to the ITU circular letter of April 1997, ten terrestrial proposals and five satellite proposals were submitted.

Eight of the proposals were variants of W-CDMA and CDMA2000. The remaining two dealt with the migration of TDMA to W-TDMA: Universal Wireless Communications-136 (UWC-136) and pedestrian Digital Enhanced Cordless Technology (DECT). This led to three main 3G-technology proposals: W-CDMA, CDMA2000 and UWC-136 to enable backward compatibility with 2G and hence protect investment in 2G.

Two partnership project groups were set up by ITU to help build consensus among the proponents of the proposals and work out specifications for the 3G. The two 3G partnership groups were:

1) 3GPP has four other Technical Specification Groups (TSG) that focuses on W-CDMA [5]
2) 3GPP2 has six TSGs that attempt to evolve the North American proposals to CDMA2000 [19].

Japan NTT was the first to implement the 3G in the last quarter of 2002. There are many other 3G vendors, but the enthusiasm for 3G is dying a natural death.

WHITHER

One of the main reasons for the clamor for 3G was the need to overcome the incompatibility of the various 2G networks. This goal was preposterous, however, given that 3G has three incompatible standards as well. Moreover, most of the capability set promised by ITU for 3G [16], such as various multimedia services and the 2 Mbps have been far fetched.

The 3GPP and 3GPP2 efforts to eliminate previous incompatibilities associated with 2G and make 3G become a truly global system were not successful. The 3G system would have higher quality voice channels, as well as broadband data capabilities, up to 2 Mbps, unfortunately, the two groups could not reconcile their differences [7], and hence multiple mobile standards. These and other reasons based on advances in electronics and optical technology has now shifted the thinking to a new generation initiative, now called 4G. It is sometimes referred to as Beyond-Third-Generations (B3G).

The 4G Forum, which now meets annually has the task of defining the migration path for 4G. The annual 4G Forum started in 2003 under the leadership of Samsung Electronics.

The 4G Vision is depicted in Figure 3. It will support open and programmable architecture, thus enabling third party developments. It will use Multi Input-Multi Output (MIMO) Orthogonal Frequency Division Multiplexing (OFDM). It will support various data rates to meet existing technologies, such as 144Kbps, 384Kbps, 2Mbps, 10Mbps, etc. The Core of the network would be IP. The emerging 4G network would be entirely packet-switched networks. It is expected to support IP end-end. It would support rates up to 100Mbps in order to carry various forms of multimedia services at lower cost. All the network elements must be digital and would be a network that is water-proof-network security.

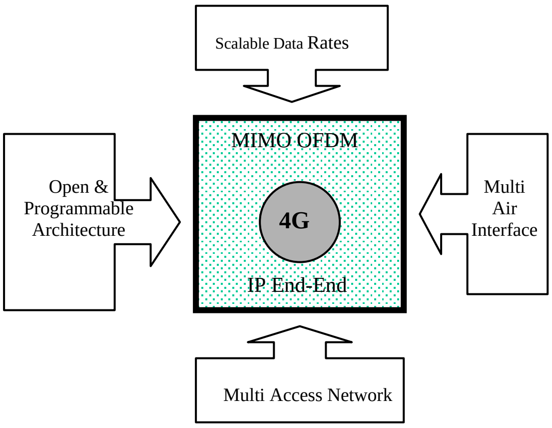

Figure 3: The 4G Vision.

The 4G system is expected to support global mobility and service portability. The network, when operational, would support location-based services, mobile shopping, e-mail, and multimedia data transfer as well as video streaming at reasonable prices. The plan is to introduce 4G services around 2010. Recently, Japan NTT Do Como announced plans to introduce 4G services in 2006, i.e. four years earlier than previously planned [15]. 4G is expected to converge different wireless systems, such as Wireless Local Loop (WLL), Fixed Wireless Access (FWA), Wireless Local Area Network (WLAN), Personal Area Network (PAN), WiMax, Universal Mobile Telecommunication Service (UMTS) Terrestrial Radio Access Network (UTRAN), etc.

B3G or 4G is currently a very active research area. A detailed discussion on the vision for 4G was given in [9, 10, 11]. Yang et al [12] considers in detail the combination of MIMO-OFDM with multiple antennas and concludes that this multiplexing technique is a very suitable and efficient method for high-data-rate wireless transmission. The application requirements and challenges of the B3G/4G were explored in [13] and some solutions were proffered for the emerging system. A major aspect of the 4G vision is its envisaged open wireless architecture. The 4G would support [14] varied access methods, multi-standard air interface, scalable data rates, scalable architecture, etc. The 4G is expected to be 2 – 5 GHz technology.

OBSERVATION & RECOMMENDATIONS

The research for 4G poses great challenges for developing nations. Telecommunications business would be dictating future business for a long time to come, but third world nations play little or no active role in the definition of infrastructures of tomorrow. This paper is intended to stimulate the consciousness of the developing nations in this direction. It is to be pointed out that after the world has already embraced 3G, the operators in most developing nations such as Nigeria were beginning to deploy 2G. Furthermore, the 2G switches deployed by most operators were circuit oriented rather than packet technology. After almost 4 years, legacy switches were no longer in use in advanced nations are still being deployed. This is a challenge to the relevant engineering institutions in the developing nations, the telecom companies, and the governments of these nations to create a forum to enlighten and keep stakeholders abreast of current technologies.

We saw earlier that companies in the industry made most of the proposals and developments in advanced countries. As an example, take TIA in the US which was responsible for submitting three 3G proposals to the ITU. TIA is a consortium of telecom companies with the staff of each company playing active roles in the definition and specification of the next generation networks. Similarly, the ETSI is an EU funded standards body with members from companies in the industry and educational institutions. The Association of Telecom Companies (ATCOM) in the developing nations should emulate what TIA is doing in the US. ATCOM could get its employees involved in some level of research, no matter how small it is. The 4G discussions are currently going on and companies in developing nations have no participation in it, and consequently, that will mean that poor investment decisions will probably be made for years to come out of ignorance.

The governments of developing nations should be encouraged to set up research bodies, just like the EU is doing with ETSI and like other government funded research projects are doing in most countries in important areas such as telecommunications. ATCOM and other engineering institutions should work with the leadership of academic institutions to accomplish this goal. This would raise research consciousness among lecturers and other academics.

CONCLUSIONS

Telecommunications technology is evolving at a rapid pace due to unprecedented advances in electronics and optical technology. This rate of change is also a catalyst for new thinking in the industry and demand for new high bandwidth services. Mobile technology generations have evolved in two decades from 1G to 3G. While each generation infrastructure is supposed to have a life of about 20 years or more, this has not been the case. The 2G failed because of its lack of support for high bit rates and the incompatibility of the different networks in different countries. On the other hand, the 3G technologies were expected to ameliorate the ills of 2G, but the very many proposals aimed at evolving the 2G to 3G left many incompatible 3G standards as well. Moreover, the various 3G systems have not met their promised capability set of delivering up to 2Mbps and of supporting various variations of multimedia services. This has propelled the quest for a new generation of mobile network known as 4G or B3G. This new initiative is currently being defined, but it is projected to support any-service, any-where, and any-time.

The emerging 4G would be made of entirely packet-switched networks. It is expected to support all IP end-end. It would support rates up to 100Mbps in order to carry various forms of multimedia services at lower cost. All the network elements must be digital and would be a network that is water-proof-security. The 4G would support global mobility and service portability. The network, when operational, would support location-based services, mobile shopping, e-mail, and multimedia data transfer as well as video streaming at reasonable prices. The 4G is also expected to support varied access interfaces such as WLAN, WLL, various Radio Access Networks (RAN), Base Station Transceivers, etc. The 4G is the future! This paper presents the vision for the next generation networks.

Telecom is the driving force of most businesses in the world and it will continue to be so for years to come. It is therefore a pivotal field that any developing nation must follow jealously. It is therefore recommended that the telecom associations of developing nations should engage in some level of research in other to keep abreast of current thinking and trends in the industry. The governments of the developing nations should also follow the lead of many industrialized nations and set up bodies that would support research, particularly in telecommunications, so that through government means, the industry may be well informed.

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