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Invited Paper

Will Wireless Communications Come to an End?

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Because of the rapid growth of the Internet, we are currently heading into the information age. High-speed data transmission for wireless communication is becoming increasingly important, especially for mobile terminals. This is because a high rate of speed requires a wide bandwidth, and the spectrum bandwidth is a precious commodity in wireless communications. It is very expensive to provide a data rate of more than one Mbps. For this reason, the question is raised: "Will wireless communications come to an end? " The answer, of course, is no. However, many problems lie ahead, waiting to be solved. Some of these problems are due to Mother Nature's limitations, some require technology breakthroughs, some are service creation strategy issues, and some issues are impacted because of the government's role. The future need of wireless communications is wide bandwidth for multi-media, such as voice, data, video, and image transmission. Designing the wireless information superhighway for the last 100 meters can satisfy this large bandwidth requirement. The demand and capacity requirements of a long communication link lead us to consider a hybrid system that combines wireline and wireless.

1. INTRODUCTION

One hundred years ago, in 1897, Marconi successfully set up a wireless communications link 18 miles long from Needles, on the Isle of Wright, to a tugboat. Today, wireless communications has become a part of our daily lives. It is, therefore, appropriate to address future trends in wireless communications.

During the past 30 years, the wireless communications industry has been growing very rapidly. Pagers, cordless phones, satellite communications, cellular phones, and PCS phones have become popular services. Among those services, voice has always been the main focus of service for customers. Even when responding to a page, a phone device is used. However, in the future, due to the growth of the Internet, data services will become important.

Digital transmission, including voice, data, computing, and entertainment, rely on high-speed data transmission. However, high-speed data transmission requires wide bandwidth, and in the wireless communications medium, bandwidth is a precious commodity. It is almost impossible to achieve bandwidth as wide as that provided by optical fiber. Therefore, the question is raised, "Will wireless communications come to an end?" Before we can answer this question, we must examine some key factors and problems. If we can

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find solutions to these problems, then the answer will be clear. The major concerns regarding the future of wireless communications are Mother Nature's limitations and human factors. Mother Nature's limitations consist of the limited natural spectrum, demand and capacity issues, technology efforts, and intelligent systems. Human factors consist of service creation and the government's role as stated in the following sections.

2. LIMITED NATURAL SPECTRUM

First, the spectrum of electromagnetic waves is a limited natural resource. Therefore, efficient use of the spectrum is a big challenge. In wireless communications, there is only a limited number of service systems that can operate because of radio interference within its own allocated spectrum and in neighboring spectrum.

In the1970's we hoped that a new discovery, gravitational waves, might provide a new spectrum and help us to develop another means of communication. However, we lost hope in gravitational waves because the experiments could not be repeated under exactly the same conditions. Of course, we still don't believe that only two types of waves for wireless communications (acoustic and electromagnetic) exist in the universe. We continue to hope that a third type of wave that has a wider spectrum and travels faster than the speed of light can be found in the future. However, today, we must continue to manage with our limited spectrum resources.

Currently, many systems efficiently use the spectrum by using spread spectrum (SS) modulation. SS modulation spreads signal energy across the wideband spectrum. It doesn't cause interference but does raises the noise floor. If all SS systems share the same wideband spectrum, the noise floor will rise to such a high level that no system can operate. Fortunately, there is natural evidence that the data transmission rate can be raised as the link is shortened shorter within a given spectrum bandwidth. We will study this evidence for application in future systems.

3. DEMAND AND CAPACITY ISSUES

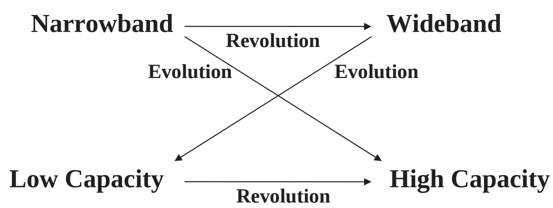
We found that voice quality and system performance, including data transmission, are inverse proportionally to service demand and system capacity:

$$\text{(voice quality and system performance)} \propto \text{(service demand and system capacity)}^{-1}$$

Although it is a fact that it is a great challenge for system operators to find new technologies to raise the bar such that voice quality can be maintained with increasing service demand.

We need wideband channels to improve capacity and high-speed data transmission. Therefore, achieving wide bandwidth will be a key challenge for wireless communications in the future.

The future trend in wireless communication is depicted in the following diagram:



There are two processes: revolution and evolution. Today, the change of the narrowband system to the wideband system, as well as that of the low capacity system to the high capacity system is a revolutionary process. Other existing systems can go through the evolutionary process, such as the narrowband system, in order to achieve high capacity, or low capacity system to achieve wideband services. The G3G (global third generation) system is currently changing from a narrowband, low capacity system into a wideband, high capacity system through a revolutionary process.

4. TECHNOLOGY EFFORT

Before a third type of wave can be found, technology efforts should be directed towards finding ways to utilize the EM spectrum efficiently.

A. Wideband Radio

Wideband radios are needed for high-speed data transmission. There are two kinds of wideband radios. The hardware radio is one kind, and the software radio is the other. The software radio can be used more flexibly than the hardware radio in the following applications:

1. One wideband radio for one service such as cellular or PCS: this can provide wideband (WB) channels or narrowband (NB) channels, or mixed WB and NB channels.
2. One wideband radio for multi-services (such as cellular, PCS, satellite, etc.): in this case, the radio can provide one service at a time, or provide multiple services at the same time.
3. One wideband radio for multi-systems (such as CDMA, GSM, AMPS, etc.).
4. One wideband radio for multi-services and multi-systems: this radio must continue to maintain good voice quality after acquiring the desired signal through its intelligent search discriminate all the undesired signals. It is a challenge.
5. The technology needed for the software radio is still in the research and development stage.

The WB software radio will be difficult to realize and will require a breakthrough in technology.

B. In order to apply wideband communications to fast data transmission, FAX, video, etc., a wideband spectrum is needed. In wireline communications, the trend is to move from twin leads and coaxial cable to wideband fiber cable. In the early 70's, fiber cable loss was very high. Technology drove the fiber cable loss down to 0.1 dB per kilometer, which is the level today.

In wireless communications, a wideband spectrum can only be provided at higher frequencies. The frequency ranges have been moved up from HF, VHF, and UHF to microwave and infrared. However, the propagation loss for microwave and infrared communications today is very high, and their links must be line-for-sight. In the future, we may find different ways to reduce this loss by deploying special kinds of reflectors or other apparatus in the field. The same trend we went through in reducing the fiber cable loss would be taken in reducing loss in microwave and infrared links.

C. Within the allocated spectrum, maximizing system capacity is the other challenge. Spread spectrum modulation has proven to be a better way to increase system capacity.

D. In order to reduce interference, the sharp skirt filter, the broadband linear amplifier, etc., need to be improved to stop interference caused by neighboring spectrum users. Supercondictivity technology may play a role in this area.

E. The wideband communication system may have to be a hybrid system which employs fiber cable. The majority of the links in a communication network are made using fiber cable. The concerns are only the connection between the fiber cable and the radio link at the last 100 meters. Technology for the last 100 meters of wireless wideband may be much easier to develop and will not only be suitable for portable applications, but also for mobile applications.

F. Intelligent Systems-A good network structure for wireless networks can be developed by (1) understanding the limitations of Mother Nature, (2) using ingenuity through human effort, and (3) taking risks in software development. An intelligent system should be all three parts to be intelligent.

The subscriber unit should be intelligent enough to execute orders. The cell sites have sufficient intelligence to pass on these orders, and the network has sufficient intelligence to execute orders or commands.

5. SERVICE CREATION STRATEGY-TIMING ISSUE

Wireless communications can be divided into two kinds of services: fixed and mobile. Fixed services use microwave links between line-of-sight terrestrial points, HF links through the ionosphere, satellite communications and wireless local loop (WLL).

A. In the area of fixed wireless services, WLL Service was started after cellular phone service was deployed. The approval of AT&T cellular service was delayed for over 10 years due to its rival's petition to the FCC. As a result, AT&T had to give up and let the seven RBOC's start the service in 1984. If the AMPS system (Advanced Mobile Phone Service) developed by AT&T had been deployed as a WLL system in the 1970's, there would not have been a struggle to deploy the same system as a cellular phone system in the 1980's. If this strategy had been deployed by AT&T, the situation in the entire wireless communications industry today perhaps would be quite different. The FCC in the 1970's might have found that providing a chunk of spectrum for WLL service was very easy, just as it was to allot a large chunk of spectrum to the television industry. Later, the same WLL spectrum could have been shared with the cellular telephone systems. Cellular telephone service could have grown quickly and quietly before public realization of the change. This illustrates the importance of timing in creating a new service.

B. In the wireless mobile communications industry, we wondered why paging service was not popular in the 1960's or 1970's in rural areas. The reason was that paging services required the use of telephones to call paging companies and to respond. Without the appropriate telephone systems in these areas or countries, paging services could not be widely accepted.

C. Mobile satellite systems were developed for global wireless communications services and to enhance cellular or PCS phone services. These systems are being further developed at the right time and will add value to wireless communications.

D. We would now like to provide wideband wireless communications services; however, until fiber cables can be deployed nationwide, the advent of wireless services using 100 meter links in a hybrid system will be delayed.

6. THE GOVERNMENT'S ROLE

With today's rapid developments in communications technology, the government should play a key role in guiding us in the right direction.

A. Auction Policy:
The government claimed that by adopting an auction policy, it avoided previous awkward situations that occurred during the lottery period. As an example, many housewives and medical doctors won lotteries and then resold the licenses they had won at a substantial gain. Since we have found the lottery policy to be disadvantageous, and since no advanced countries follow the U.S. lottery policy, we should return to the earlier practice, where licenses were selected based on three requirements; technology competence, financial strength, and good service for the public, as do all the advanced countries.

The spectrum is like air — a universal commodity. If we pollute the air, people will die. If we pollute spectrum, wireless communications will die. The government should establish regulations to protect "clean air" and "spectrum non-interference," but the government does not own the air or the spectrum. Currently, the government sells a spectrum it doesn't own and generates income through the auction process, which means passing ownership of unowned spectrum to individuals. Since the government has become a profit center, it has no power to discipline its customers, the auction winners. The winners may again sell a portion of their spectrum to others. The element of spectrum coordination in the FCC is lost.

In the future, auction winners will be able to either pass the cost of the auction on to end-users or will provide poor service. The auction winners can always blame the government for putting such a big burden (the auction cost) on them before investing capital in the business. This is why advanced countries prefer to tax the service providers afterwards based on their profits.

If the government feels that this auction money comes at no cost, it is wrong. The government should be cautioned not to use auction profits before systems are built. Businessmen may someday ask the government to return the auction profits if business is not going well. Remember that the government is not a profit center.

B. Standard Setting and Spectrum Coordination

The FCC does not want to be involved in choosing the standard setting. In broadband PCS, there are four systems to choose from. This means that four systems could be operated in one service in the same geographical area. The consequences are as follows:

1. The service provider will worry about interference from other systems in one area. In the past, one system was always standardized in one service. For instance, AMPS was used for the U.S. cellular phone service. However, today, for the first time, multiple systems can be operated in one service. Therefore, the old rules of spectrum coordination cannot be followed or enforced.

2. End-users will pay high costs due to the low volume of terminal production for using only one of four systems. Of course, no roaming can be done among the four systems.

3. The FCC may be unable to solve disputes regarding spectrum interference among the different service providers.

Without the FCC as an effective entity disciplining spectrum usage, the future of wireless communication may resembel a situation in which vehicles jam an intersection. No vehicles can more...GRIDLOCK!

C. Spectrum Flexibility

Currently, the FCC has a policy of encouraging spectrum flexibility. This can be classified in two ways — service flexibility and technical flexibility. The purpose of this policy is to promote competition and the public interest by using the spectrum more efficiently. Service flexibility serves more services in an allocated spectrum in the same geographical area. Technical flexibility serves different technology systems in the same spectrum band and the same geographical area. This does cause some concern. This flexibility policy can lead to two situations — instability and a lack of discipline. This needs further study.

D. The Risk of a Newly Developed System
Great risk is encountered in the development of any new system. Both vendors and service providers will go through a learning curve and will pay unexpected costs. Some developing systems may never operate as expected. Also, vendors may lack the patience needed to develop a mature, standard system. As a result, some vendors will have to take risks to manufacture an immature system, and some system providers will have to take risks to operate it. They will all lose money at the beginning because of poor performance. Therefore, if one system is proven to be workable and mature, and meets the requirements, then this system should be adapted to realize many services. Following this approach, end-users can use one terminal to operate in different services.

E. What would be a good international standard? A good standard system should be used by many different services, as shown in Fig. 1. The four services, PCS, Cellular, LEO/MSS (low earth orbit/mobile satellite service), and WLL (wireless local loop), use one system. This would be a desirable solution. The most undesirable situation would be to have numerous systems providing the same service.

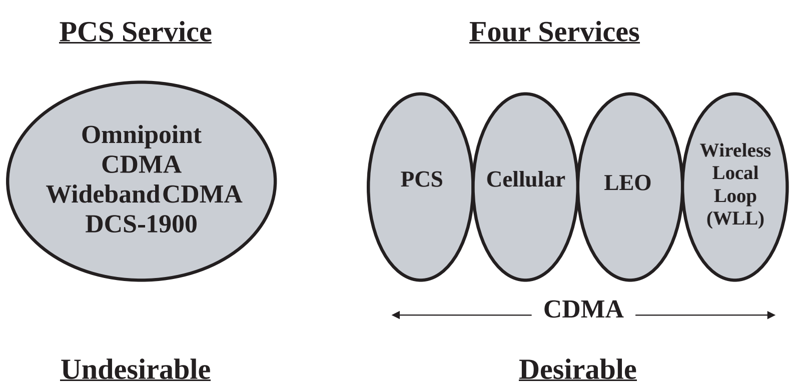


Fig. 1. The two cases in system standards.

Also, a good system should serve the subscriber's interests as follows: low cost, high quality, small size, light weight, long talking time, calls can be reached anywhere and any time, and the unit is easy to handle and operate. The one-unit concept is shown in Fig. 2.

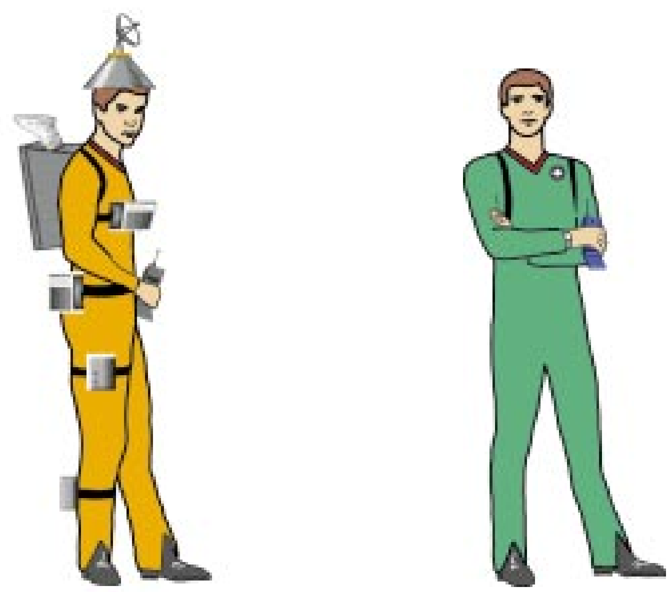


Fig. 2. One unit concept.

7. WIRELESS INFORMATION SUPERHIGHWAY

The information superhighway concept came from Al Gore. The wireline information superhighway can be realized because of the huge bandwidth gained from fiber optic networks. The only human-made issue is network access. Developing an access scheme to get on, and off the information superhighway is a challenging task. On the wireless information superhighway, limited bandwidth stems from a limitation of Mother Nature. Also, mobility creates another obstacle to achieving high-speed data transmission. In order to obtain wide bandwidth, the carrier frequencies must be up to millimeter wave or to the infrared spectrum region as shown in Fig. 3. Over the millimeter wave links, we can apply the diversity scheme to increase the signal strength. Over infrared links we can use diffuse transmission to create multi-path conditions and operate under out-of-sight conditions. Also, because infrared can penetrate rainfall but not fog, and millimeter waves can penetrate fog but not rainfall, we can create a dual-medium diversity receiver that uses both infrared and millimeter waves for the last 100 meter wireless high-speed data link.

8. CONCLUSIONS

Many areas of concern have been mentioned. If a new, undiscovered wave medium cannot be found, if the technology effort cannot be moved ahead, if the service creation strategy timing is incorrect, if government does not play a strong role in spectrum coordination, and if demand and capacity are not well thought out and planned, we may not be able to make progress in this industry.

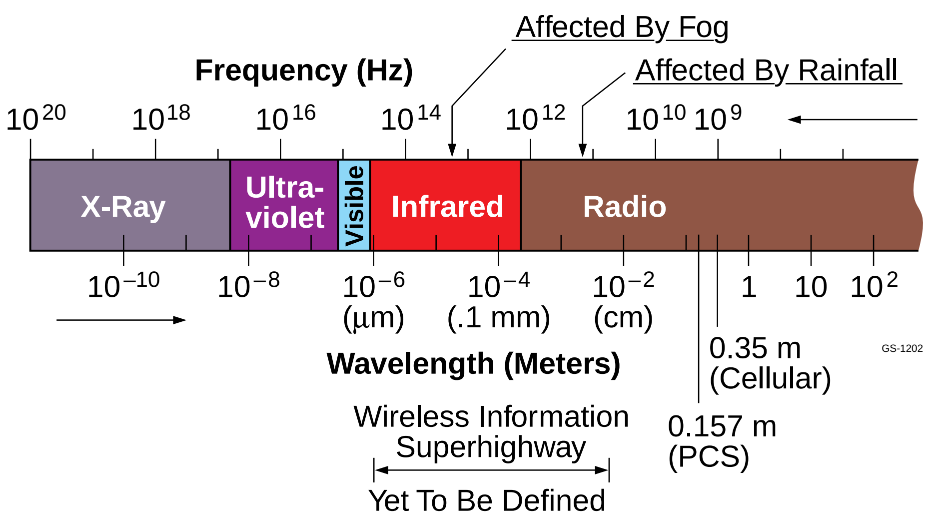


Fig. 3. Infrared band.

Of course, by making everyone aware of the various problems that lie ahead and by addressing these problems early on, we will be able to correct our course as we move forward into a great wireless communications future!

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