Shape of Future Wireless Networks

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Abstract

This paper describes the future development of wireless networks. The paper highlights the existing incompatibility between the wired and the wireless parts of the network when it comes to satisfying future applications. The paper focuses on the evolution paths so that wireless and wired parts of the network could work in harmony. The migration paths from second to third and to the subsequent generations of wireless systems are described. The needs of users beyond 2010, when the next generation of wireless networks are expected to emerge. The paper evaluates the impact of Internet on the shape of future wireless networks and its interconnection in the next generation networks. The paper will present some scenarios on wireless access, network architectures, the requirements on management of resource and mobility resulting from seemless roaming between different sectors of integrated network.

1. Introduction

The wireless networks have gone through an unprecedented growth during the past few years, and this growth rate is likely to continue at the current level or may even surpass it following the introduction of 3G systems. The five 3G air-interface standards were approved by ITU-R Forum in 1999. The two standards, IMT-DS and IMT-TC, based on WCDMA are entirely new whereas the other three standards, IMT-SC, IMT-FT, and IMT-MC, are to evolve from the 2G systems IS-95, DECT, and GSM (and IS-136) respectively. The first 3G system in the form of IMT-DS (and IMT-TC) will be commercially available in Japan at the end of April 2001. Operations in Europe will follow next year.

The services envisaged in 3G systems have been defined in terms of peak transmission rates for three different types of environments. For example, 3G systems will allow a maximum data rates of 144 kbits/sec for terminals that move fast. These terminals are probably vehicular based. For slower moving terminals, the peak transmission rate has been defined as 384 kbits/sec. For static or extremely slow moving terminals, a peak data rate of 2 Mbits/sec is defined. Obviously, the services offered in the three defined environments are likely to be different in data rates and quality of service. Unfortunately, the aim of achieving uniformity of services under all operating conditions may not be achievable in the current series of standards. The introduction of 3G systems will shift the services' scenario from voice to integrated voice, data, and image services. The idea is to give the users some control on the service choice and quality of service (QoS). We believe that all those services envisioned for 3G systems can not be offered and in that respect several shortcomings in the 3G systems will remain.

The past history of developments in wireless systems indicates that a new generation of wireless systems emerges approximately every ten years. Projecting to the future, we expect that by 2010, a new generation of wireless systems will be in operation. It is not yet clear about the final form of the 4G systems. This is currently a subject for intense debate and speculation. This paper takes a systematic approach in making projections on the form of 4G systems.

We begin with an analysis on the recent trend in services. Such analysis will point to the shape of future networks. The services currently being offered in the fixed networks provide the starting point because these services will probably be offered by wireless network when convergence between the two networks takes place.

The main aim of the future wireless networks is to strive for total integration so that it becomes possible to provide ubiquitous communication between points regardless of their location and time. Wireless systems have two main parts – wireless part and the wired part. For a successful operation of these systems, the components must work in harmony, that is there must exist a high degree of compatibility so that many telecommunication services could integrate without incurring high costs of interfacing networks, multiple standard terminals, and protocol translators. To determine the future development in wireless networks, we must take account of what is available to date and what is needed to make progress towards the next generation. The major issues which emerge when we try to make the wired networks to work in harmony with the wireless networks are interoperability between heterogeneous networks, networks architectures, traffic mobility management, and protocols to be used on the air and in the network.

The rest of the paper is organized as follows. In the next section we shall discuss issues related to wireless access and technologies needed to allow services expected in the future. Section 3 discusses the current status of the wired network and various options for its evolution so that it meets requirements set for the applications expected in the future. The question on how to handle heterogeneous traffic will be discussed. With this scene set, discussion moves the scenarios that will allow wired and wireless networks to tick together. This is discussed in Section 4.

2. Issues Related to Wireless Access

Our objective to make the wireless and the wired parts of the network in harmony. Thus, our aim is to identify the areas of incompatibility between the two networks. The ways to increase the compatibility will be discussed in this section.

2.1 Wireless Link Bandwidth Limitations

The first issue that comes to mind is incompatibility between the data handling capacities of the wired and the wireless parts of the network. In the case of wired networks, the addition of bandwidth is added to the network by simply laying a new cable, or fiber. However the bandwidth resource of the wireless link can not be increased without adding new spectrum. Considering that the spectrum is a finite resource, it is not easy to add to the existing spectrum. Even if some spectrum becomes available, the radio environment imposes limitations on the data rate that could be sustained on the wireless link. This is clearly a hurdle in the way of achieving high data rates over these links. In the light of projections that the new services will result in a substantial increase in demand for resources, we may not have any other alternative except to seek methods to create additional resources.

Unfortunately the wireless resource is fixed and it is always shared. It is finite; therefore efficient use of the resource is essential. This fundamental limitation of wireless bandwidth keeps the realm of wireless communications beyond the reach of Moore's Law of doubling of computing power every eighteen months. The computing capacity is advancing and with it new services are created, which will be offered by the wireless networks. Thus, we need to increase the wireless capacity. The limitation in the bandwidth arises because of the presence of channel fading, multiuser interference, power limitation, etc. These limitations must be reversed so that new bandwidth for use is created.

One alternative is to make the use of bandwidth more efficient. That is, how to increase the capacity of wireless link given that no new spectrum will be available. Creation of bandwidth (or increasing the wireless link capacity) will bring closer the data handling capacity of the wireless and the wired parts. Once this is done, we shall begin to explore how these two parts will work together in harmony. We shall then explore the potentials of the networks for new services.

Fading counter measures in the form of error control and interleaving provides a classic method to increase the data handling capacity of the link. The fundamental principle of improving the reliability of the link increases the capacity of the link. Techniques like spread spectrum provide performance gains because of implicit frequency diversity. Similarly, implementation of space diversity (micro-diversity and polarization) enhances the performance and thus capacity of the wireless link. Even multiuser signaling can enhance capacity. For example, higher spectral capacity can be achieved by transmitting a number of signals instead of transmitting a single signal of power equal to the sum of powers of all signals.

The antenna arrays require lower total transmit power and can minimize interference by reducing channel delay spread. The use of multiple antennas at the transmitter and the receiver can also be used effectively to increase data capacity several fold. For example BLAST (Bell Labs Layered Space Time) that uses eight transmit and eight receive antennas when combined with non-linear multiuser detection increases the spectral efficiency of the order of 40 bits/sec/Hz.

The presence of interference limits the channel capacity. Interference suppression results in higher spectral efficiency. Fortunately, the multiuser interference has a structure and exhibits less randomness than the Gaussian noise. Therefore, its structure can be exploited to increase spectrum efficiency, receiver sensitivity and capacity. Multiuser detection is a technique, which can pay handsome dividends in the form of increased capacity. Unfortunately, the multiuser detection receiver structures are complex and remain expensive. New methods are being sought to reduce the complexity of these receivers.

2.1 Wireless Access Technologies

The wireless part of the network consists of links, which are established between wireless terminals and network nodes. The access method, and signal transmission over these links are the subjects of this section.

2.2.1 TDMA, CDMA, and OFDMA

The future wireless access is likely to be packet oriented. CDMA, TDMA, and OFDMA are suitable multiuser technologies that can be used to provide linkage between mobile fixed network node. The TDMA, and to some extent high speed CDMA (WCDMA) are susceptible to channel delay spread particularly when data rates of in excess of 2 Mbits/sec are needed.

The single carrier TDMA solutions to support high-speed data are limited because of higher complexity of equalizers. Furthermore, in the case of fixed bandwidth CDMA solutions, the spreading gains are related to the bit rate. The high bit rates have lower spreading gains; thereby the quality of service suffers. In this case, the implementation of power control takes a different dimension, because the users must be categorized in terms of data rates to form sets consisting of users with equal data rate, before power control is implemented. Since the spreading ratio is low for high-speed data, low spreading gain, and inter-code interference are likely causes of service degradation.

OFDMA systems having speeds up to 30 Mbits/sec in 5 GHz band have been successfully implemented in wireless LAN. OFDMA with symbol duration of 100 to 200 μsec (number of carriers between 200 and 400) can eliminate the effect of ISI envisioned in 3G systems when operating in the three types of environment. The OFDMA technique is also amenable to implementation of interference suppression solutions like parallel, and successive interference cancellation. Simplicity of implementation of space-time coding to enhance capacity, and efficient high-speed wireless packet data access are the other two good features of OFDMA. OFDMA can also work with Dynamic Packet Assignment (DPA), adaptive modulation, and coding that conform to different bit rates. This has flexibility of providing varying efficiency and robustness. Integration with GPRS, EDGE the two solutions suggested in migration paths for IS-136 and GSM can be implemented. Similarly, integration with WCDMA can be done easily.

2.2.2 Wireless Self Organizing Networks

Network access by the wireless terminals can be obtained in two ways. First, the wireless terminal can access the fixed network via base stations. This option requires considerable investment in the infrastructure, which consists of hundreds of base stations dispersed over the coverage area. This is called single hopped systems and is typical of wireless cellular systems of today. The other alternative is to access the network via multiple hops leading to a super node. The infrastructure cost can be avoided by using dispersed mobile terminals to reach the network node. Such networks known as wireless ad-hoc networks are being considered to the future generation of networks. In this architecture, the cost of network is considerably reduced but since the network functions are imbedded in each terminal, these terminals will be of higher cost.

For these networks, three types of network topologies can emerge – static, static multi-hop, dynamic multi-hop. Static topology relies on one hop communications. This topology implies that link parameters do not change much and the link remains static for the duration of the link. The network requires several controls for satisfactory operation. Power control is needed to maintain adequate signal level at the end of the link, controls for network access and admission to maintain authentication and security, and multimedia control to determine the type service required. In addition, global control, error control, congestion control, and degradation control are needed for the network to operate satisfactorily.

The second possible topology is also static but the information transport is through multi-hop communications. This topology requires all the control stated above with additional controls on path, routing, reconfiguration and channel assignment.

In the presence of terminal mobility, the network topology becomes dynamic. The dynamism in the network requires further controls on terminal location, adaptive topology control, and adaptive base station control. This scenario is the most complex.

One example of dynamic topology is wireless adhoc network called Terminode. This network is based on the forward line wireless network proposed by DARPA. This project was initiated last year and will end in 2010. The network will cover a wide area and will be totally wireless network. All network functions are imbedded in the terminals – hence the name Terminode. The network will be autonomous and self-organizing and will be independent of any infrastructure or other equipment. The wireless technology will be derived from Bluetooth and the Terminode will cover all layers – physical to application. The networking functions that are performed in backbone routers, switches and servers are distributed in Terminode.

The advantages of this type of networks lie in scalability to large numbers, decentralization, and self-organization. Terminode will be a connectionless packet switched network. An End system Unique Identifier (EUI) encoded using 64 bits will be assigned to each Terminode. A temporary location dependent address consisting of triplets of geographical location (longitude, latitude, and elevation) is obtained from GPS receiver, which is imbedded in the Terminode.

3. Issues Related to Wired Networks

The current core networks are optimized for speech communications The advantages of circuit switched networks are reliability, add-on features, and compatibility with most domestic and international phone networks. However, the data traffic has been rapidly increasing and its volume over the fixed has now overtaken the voice traffic volume. For greater efficiency and better management of network resources, packet transmission has been found to be more suitable. Thus, the circuit switched networks need to go through some evolutionary changes to accommodate rapidly increasing data traffic. In this regard, some of the optimization parameters currently used in the voice networks will be changed so that the network becomes more suited to packet services.

The trend of using IP telephony for services that include voice, data, video streaming, and video on demand is a major force in bringing evolutionary changes to the wired network. Sony, IBM Japan, and Fujitsu have struck a partnership and proposed IPv6 Internet protocol, which allows integration of these services. The new protocol (Ipv6) will also allow Internet access through television and other electronic devices found in home. The IPv6 protocol will allow an increased number of IP addresses. This will enable integration of devices, computers, and even transportation systems etc.

It should be recognized that the network would not be transformed from purely circuited switched to purely packet switched network due to obvious reason of existence of voice and data traffic. The voice traffic is better served by circuit switching but packet switching is more suited for data. It is expected that a near term evolution will result in hybrid network architecture. In the hybrid architecture, the network will have two UMTS core network domains. The Circuit Domain is based on enhanced GSM mobile switching centers (E-MSC's) and Packet Domain will be based on enhanced GPRS support nodes (E-GSN). The HLR (Home Location Register) holding subscriber data will support both domains. Figure 1, shows simplified UMTS Release 99 Architecture.

Iu interfaces between Access and the Core network (Iu-CS and Iu-PS) are provided for both types of traffic. The hybrid nature of the network is most evident in transport and call control planes. Voice communications handled by PSTN and ISDN is complemented by a sophisticated GSM/UMTS specific service architecture based on IN principles – for a wide range of supplementary and value added voice services.

The IP connectivity is provided as a pure network –layer service between a UMTS Mobile station and an Internet host. Cellular radio and mobility enhanced bearers are the opening stage for a variety of IP based application.

4. Harmonization between Wired and Wireless Parts

The fourth generation system will try to harmonize operations over the air interface and in the fixed network. The envisioned capabilities of a 4G system are shown in Figure 2. It does not mean development of new technologies for the air interface or the network, but it implies working together of air interface and the fixed network, even when the data rates increases by ten times. It also means that seamless services will be offered on global basis.

The quality of service remains a paramount concern. To achieve uniformity of service quality is a major challenge in wireless communications. How to control the quality of service in the presence of major quality degrading factors such as interference, and channel frequency selectivity.

The fourth generation network will evolve from the existing networks and an example of 4G-network architecture is shown in Figure 3. In this figure the relation with the current networks is also shown.

Conclusions

The paper described future development of wireless networks. The data rate incompatibility between the wireless and wired part of the network is highlighted. Various means of enhancing capacity are described. The future shape of 4G systems is envisioned and described.

It is concluded that the future network will consist of both the circuit and the packet switched modes. An example of new network architecture for 4G system has been presented.

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Figure 1 UMTS Release 99 Architecture

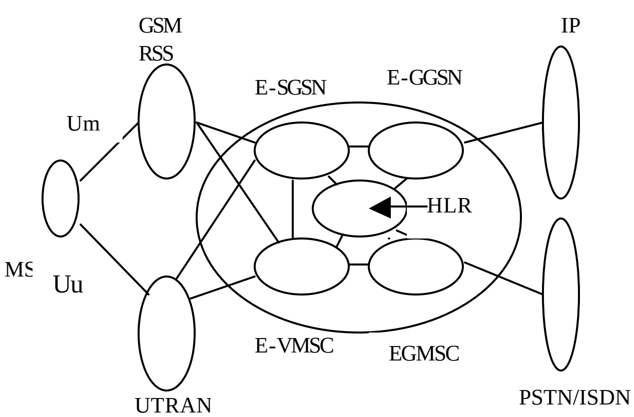

Figure 2 Defining the Capabilities of 4G systems

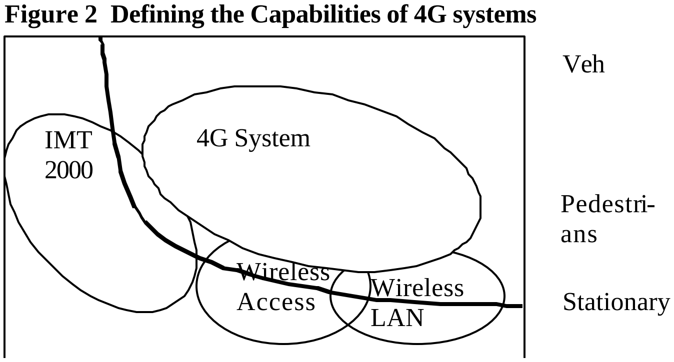

Figure 3 An Example of 4G Network Architecture