QoS Management and Peer-to-Peer Mobility in Fixed-Mobile Convergence

● Wei-Peng Chen ● Takeo Hamada ● Jason Jeyhsin Yao
● Hung-Yu Wei

(Manuscript received April 8, 2006)

Next-Generation Networks (NGNs) and Peer-to-Peer (P2P) are the two driving forces of Fixed-Mobile Convergence (FMC). The complementary nature of NGNs delivering controlled services and P2P with the intrinsic characteristics of overlay services, which does not require large-scale infrastructure investment, is important for cost-effective and rapid deployment of FMC. For the successful deployment of FMC, a coherent and universal approach toward QoS and mobility management is particularly important. In this paper, we propose QoS and mobility management mechanisms for various wireless networks, including 3G, 802.16 Mobile Multihop Relay (MMR), 802.11 mesh networks, and WiFi/WiMAX relay networks. We also discuss enhanced P2P mobility schemes for achieving session continuity and seamless handover.

1. Introduction

Recent advances in the communication technology of optical and wireless networks provide broadband service to users and promote fast growth of network usage. The network architecture of Next-Generation Networks (NGNs) incorporates both optical and wireless networks, enabling Fixed-Mobile Convergence (FMC), which is the integration of wireline and wireless networks. When this is achieved, FMC realized through NGNs will not only enable network operators to utilize deployed equipment more efficiently but will also provide ubiquitous and seamless network access to users. Several common FMC scenarios will become reality soon. For instance, a single handset will be able to function as a mobile phone, a home phone, and an office phone. Another scenario would be a ubiquitous set of services commonly accessible through any type of device, for example, an office phone or a mobile handset. The key for these scenarios is a convergence of fixed and mobile networks that enables new features that work irrespective of location, access technology, or user-interface device.

1.1 NGNs: Keys for transition to IP networks

NGNs are being standardized at the ITU-T NGN Focus Group.[1] NGN Release 1, which was issued in November 2005, is based on the IP Multimedia Subsystem (IMS). In this paper, we propose IMS as a technology standard for realizing the architecture concept of NGNs.

With the advent of broadband services, inexpensive VoIP services with good quality have become increasingly popular. The traditional telephone companies, whose major revenue source is from voice services, encounter tremendous pressure to upgrade their circuit-switched equipment to IP-based networks. IMS, which is a suite of technology standards developed by the 3rd Generation Partnership Project (3GPP),[2] provides voice, video, and other multimedia services to users across various access networks, including traditional fixed and mobile phone networks. Two main incentives attract the incumbent carriers to adopt IMS. First, it supports smooth transitions from circuit-based networks to unified IP-core networks. Second, it defines the central management functions of authentication, authorization, accounting, and charging (AAAC), which enables carriers to take control of the provided services.

1.2 Era of FMC

FMC is driven simultaneously by network operators, service providers, and customers from three perspectives. First, recent mergers of network operators to broaden their customer base and reduce operation costs are accelerating the convergence process. Second, the trend of moving towards IP-centric core networks is forcing network operators to adopt open architectures and allow connections across different carriers. Third, customer demand for an integrated service from any location with lower prices has triggered the acceptance of FMC by both service providers and network operators. In the near future, FMC could happen in three areas: terminal device convergence, network convergence, and service convergence.[3] User terminals will become increasingly powerful and will incorporate multiple functionalities of communication, entertainment, and localization. In particular, a terminal device equipped with multiple radios for different types of wireless networks will enable users to access networks ubiquitously. The grand convergence will not only happen at the terminal side but also the network side. An early effort is Unlicensed Mobile Access (UMA),[4] which provides access to GSM voice service and GPRS data service over WLAN (802.11) or Bluetooth. In addition, the IEEE 802.21 Media Independent Handover (MIH) standard[5] considers media independent handover across 802 systems and cellular systems.

1.3 Peer-to-peer service and NGNs: friends or foes?

The Internet has become a big part of human life. Ubiquitous network access and seamless handover are essential features in NGNs. In particular, integration of heterogeneous systems and provision of resilient wireless networks will enable users to access the Internet more conveniently and more reliably. Several standardization groups have been working towards this goal, including the IETF MIPv6 Signaling and Handoff Optimization (mipshop).[6] However, there is still a long way to go before standards are adopted and implemented by network operators. Peer-to-peer (P2P) technology is another driving force for the realization of FMC. P2P technologies enable end users to construct overlay networks to conduct various tasks without support from the infrastructure. Great potential exists for applying P2P to achieve goals in FMC.

P2P technology has drastically transformed the landscape of Internet traffic in recent years. P2P file-sharing services such as Napster, eMule, and BitTorrent have been widely used. Use of P2P voice streaming is growing, for example, there are now more than 100 million registered users of Skype's free service. P2P architecture offers a solution to the scalability problem often encountered by streaming networks. When a node joins a P2P network, it not only consumes resources provided by peers but also contributes its bandwidth and computation power. By relaying data over P2P networks, users receiving data also help in its distribution. In addition, the nature of overlay routing in P2P networks makes path diversity possible, and this mechanism greatly relieves the load for streaming servers and facilitates traffic load balancing. More importantly, P2P can function with little or no support from the infrastructure side. It is apparent that current P2P services, though in a limited manner, provide the basic premises of FMC. On the other hand, NGNs will eventually offer managed services that the current P2P offerings lack. In short, NGNs and P2P offer complementary benefits to the end users. Therefore, it is unlikely that one will completely eclipse the other in future network operations.

IMS and P2P approach FMC from almost opposite directions in the architecture spectrum. P2P still lacks important components to achieve FMC with reliable performance guarantee over a varied environment that encompasses both wired and wireless networks. From the NGN point of view, this may be a secondary issue because the role of current P2P services might be gradually diminished upon full deployment of NGNs. Although this scenario is probably desirable from the telecom operators' point of view, it probably will not occur. Historically, the open and unmanaged nature of the Internet has been the source of its creativity in application development as well as its technical problems such as performance maintenance. There are always inherent needs in the Internet for unmanaged resources and applications based on such premises.

To address specific technical issues in two architectural approaches, we view that the interaction of mobile users with wireless resources, both managed and unmanaged, provides the best illustration of the issues involved. In Sections 2 and 3 of this paper, we study Quality of Service (QoS) issues in wireless NGNs, and then in Section 4, we study P2P mobility management. We conclude the paper in Section 5.

2. QoS issues in wireless NGNs

IMS defines the basic QoS architecture and signaling flows, including the Session Initiation Protocol (SIP) for multimedia session negotiation and session management, Call Session Control Function (CSCF) for mobility management, and Policy Decision Function (PDF) for resource assignment. However, the implementation details for different types of networks are left to each vendor. QoS control and resource management are challenging problems in wireless networks. Especially, we address the problem of achieving QoS under new types of network architectures, including 802.11 WiFi mesh networks, 802.16 Mobile Multihop Relay (MMR) networks, and various kinds of heterogeneous relay networks. More specifically, several Traffic Engineering (TE) schemes are proposed to achieve QoS in 802.11 and 802.16 mesh networks. Furthermore, the issue of QoS mapping across different types of network is being discussed.

To ensure satisfactory user experiences, wireless network service providers strive to engineer their networking systems to achieve high QoS levels. In general, network QoS could be categorized into two types of QoS: differentiated QoS and guaranteed QoS. With differentiated QoS, network traffic flows are categorized into several classes. Network service providers give different priorities to serve packets in different classes. Data packets are classified and delivered with different service classes. Packets with delivery constraints could be sent with a high-priority class, while delay-tolerant packets could be sent with a low-priority class. Through a mechanism supporting guaranteed QoS, network resources are reserved for the traffic flows to provide QoS bounds such as bounds on delay or throughput. For example, network resources could be reserved for real-time traffic (e.g., video streaming and voice over IP flows) to ensure service quality. In wireless NGNs, the network has to support both differentiated and guaranteed QoS because, ideally, in a true FMC environment the wireless segment of the network will be indistinguishable from the wired segment.

There are three main QoS requirements of FMC for achieving end-to-end QoS assurance:

1) TE and resource reservation: Network controllers need to allocate and reserve resources according to the demands of aggregated traffic.
2) Conversion of QoS requirements: The QoS mechanisms differ in various types of networks. A mapping function is needed to convert the QoS requirements between different networks.
3) Fast handover: We need to reduce the handover latency in FMC in terms of the

forwarding time at relay nodes between networks and in terms of the handover time when an end user roams from one network to another one.

In the next part of this section, we show that appropriate QoS management is possible through radio resource management.

Radio resource management and soft QoS guarantee

A radio resource management scheme is necessary to allocate scarce wireless resources to all users and provide good QoS. The design goals of radio resource management are to improve overall system performance, utilize radio resources efficiently, and provide individual users with good QoS. Wireless channel fluctuation due to radio propagation (e.g., path-loss, fading, and shadowing) is the major challenge to be overcome in wireless network engineering. It is easier to provide differentiated QoS service to wireless users by giving priorities to different packet classes. To provide guaranteed QoS service in a variable wireless environment is challenging. For example, even though a wireless network service provider might be willing to dedicate all available radio resources to a user terminal to satisfy its QoS requirement, sometimes the QoS bounds cannot be satisfied because of severe and prolonged fading. In addition, allocating wireless radio resources to a user in a poor channel results in inefficient radio resource utilization.

Due to the random nature of wireless channel fluctuation, a wireless engineering design paradigm emerges. Instead of providing hard guaranteed QoS bounds in wireless networks, soft guaranteed QoS bounds are applied to ensure quality of packet delivery. For example, a radio resource allocation algorithm to provide soft guaranteed QoS is proposed within the WCDMA HSDPA context.[7] Radio resources are allocated in an opportunistic way so that base stations dynamically assign time slots to user terminals with better wireless signal reception. The allocation mechanism guarantees a certain amount of time slot allocation during an allocation round. Therefore, this resource allocation scheme achieves efficient resource utilization by allocating time slots to terminals in a good wireless channel and provides soft QoS with guaranteed time slot allocation during an allocation round.

3. QoS control in 802.11 and 802.16 mesh networks[8]

NGNs are intended to incorporate the existing deployed infrastructure and newly developing wireless networks. Wireless mesh networks provide a cost-effective solution and fast deployment to network operators so they can rapidly extend their service coverage. Many cities worldwide have been developing IEEE 802.11-based wireless mesh networks to provide network access to residents over a large neighborhood and connect public service infrastructures such as surveillance camera systems.[9] In contrast to the 3G-based wireless NGNs we discussed in Section 2, QoS was not always part of the design in 802.11-based wireless. Due to the urgent need of WiFi-WiMAX handover systems, it becomes necessary to provide a more encompassing QoS concept for heterogeneous wireless networks that include 802.11-based WiFi, WiMAX, and even 3G-based wireless NGN networks. At this point, there is little or no immediate convergence in these three wireless systems. We envision, however, that wireless technology convergence, which itself is a part of grand-scale FMC, would bring WiFi and WiMAX together as almost interchangeable in metro wireless operations. Convergence of WiMAX and 3G cellular networks would occur later, from which 4G wireless systems will eventually emerge.

The IEEE 802.11s[10] and IEEE 802.16j[11] groups are specifying standards for WiFi WLAN mesh networks and WiMAX MMR networks, respectively. We truly believe that one strong candidate for the next-generation FMC network architecture consists of optical networks, WiMAX relay networks, and WiFi mesh networks. An example of such an architecture is shown in **Figure 1**.

At the top level, a wavelength division multiplexing (WDM) optical ring forms the core of the metropolitan area network (MAN). At the middle level, WiMAX base stations (BSs) and relay stations (RSs) form a WiMAX MMR network that relays traffic from the lower level to the core network. The bottom level consists of WiFi mesh networks that provide high data rate connections directly to the end users. A transition point between different levels serves as a bridge between networks. Traffic is aggregated and disseminated through the transition points. Especially, the optical switch nodes on the WDM optical ring, which are also portal nodes in WiMAX MMR networks, transfer traffic between wireless networks. Similarly, each WiMAX BS/RS also serves as a portal node in WiFi mesh networks.

3.1 WiFi/WiMAX integrated service

IEEE 802.11 WiFi currently has a wide deployment base. The emerging 802.16 broadband access therefore needs to be integrated with existing WiFi technology. There are two types of integrated WiFi/WiMAX architectures. In the first architecture (**Figure 2**), WiFi and WiMAX provide complementary wireless access. Dual-mode WiFi/WiMAX users roam between WiFi hotspots and WiMAX base stations. Seamless handoff between WiFi and WiMAX is the main design issue in this integrated environment. To provide QoS in this integrated wireless network, it is necessary to map and allocate different 802.16 QoS class services to 802.11e EDCF[12] service during handoff.

In the second scenario, WiMAX is served as a backbone connection for WiFi access points (**Figure 3**). The wide bandwidth and long transmission range make WiMAX a flexible and

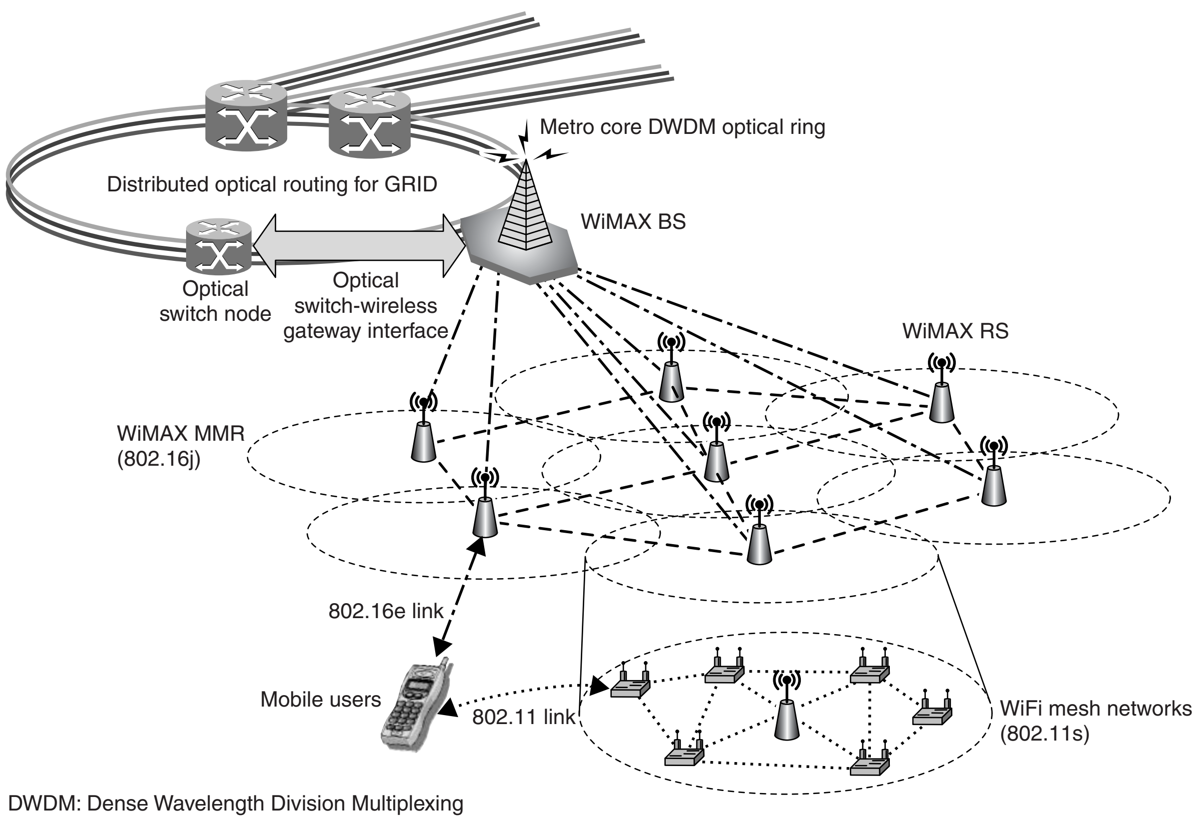

Figure 1
Heterogeneous network architecture of FMC consisting of optical ring, WiMAX MMR, and WiFi mesh networks.

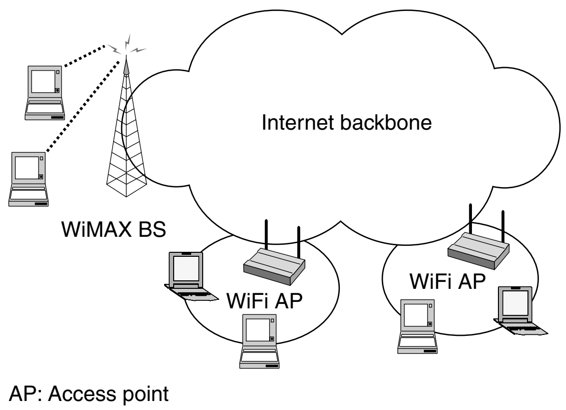

Figure 2
Integrated WiMAX/WiFi wireless access.

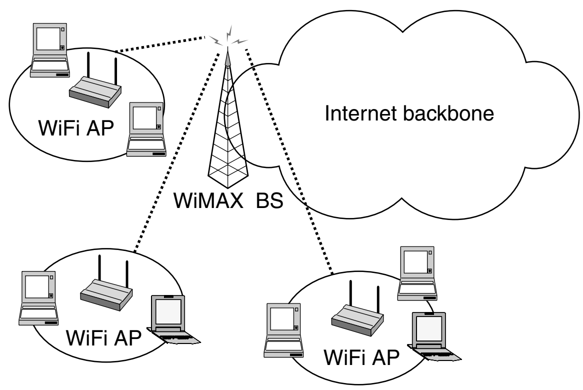

Figure 3
WiMAX as backbone connection for WiFi access points.

Table 1
Comparison of WiMAX and WiFi networks.

Item	WiMAX	WiFi
Physical layer (PHY)	OFDM/OFDMA	OFDM
Media access control (MAC)	TDM/TDMA	CSMA/CA
Spectrum	licensed and unlicensed	unlicensed
Coverage	~1 mile (~1.6 km)	~100 feet (~30 m)
Mobility	medium	low

cost-effective backbone solution for WiFi access points. Several WiFi access points are connected to the backbone network via a WiMAX base station. To provide good QoS in such a context, the WiMAX base station needs to consider traffic load at those WiFi access points and efficiently allocate both the downlink and uplink radio resources.

The advantages of multi-hop wireless mesh networks are as follows. First, the connectivity range of the core wireline networks is extended. The concept of multi-hop relay not only extends the communication range of a portal node beyond the single-hop coverage but also relaxes the ties between mesh nodes and the infrastructure. The wireline infrastructure is replaced by wireless backhauls in wireless mesh networks. Second, the deployment of mesh nodes becomes easier and more flexible, and the deployment cost is much lower than the cost of building a wireline connection. Third, the mesh networks are robust because the networks are interconnected by multiple links.

In this section, we introduce the proposed channel-assignment traffic engineering methods for WiFi and WiMAX mesh networks. Among the differences between WiFi and WiMAX networks listed in **Table 1**, the Media Access Control (MAC) and the spectrum determine the mechanisms of channel assignment. The allocated spectrum for the WiFi system is completely operated in the license-exempt (unlicensed) band, while most WiMAX systems use the licensed band. As a result, WiMAX and WiFi have different MAC designs. The MAC in WiFi is the contention-based CSMA/CA, while the MAC defined in WiMAX is contention-free. WiMAX BSs schedule time slots to subscriber stations (SSs) (i.e., in the time domain). In addition, with Orthogonal Frequency Division Multiple Access (OFDMA) physical layer (PHY), BSs can allocate a subset of subcarriers to each SS (i.e., in the frequency domain).

Channel assignment can be executed in a centralized or distributed manner. In the centralized channel assignment approach, the channels are allocated by a controller that periodically collects the topology and traffic information from the mesh nodes. Then, the results of channel assignments are disseminated to all mesh nodes for further adjustment.

In the distributed approach, each mesh node decides which channels to use based on the local information, including the topology, channel conditions, and traffic conditions. The distributed approach is simpler and more robust than the centralized approach. Nevertheless, the low channel utilization and lower controlled usage of resources might degrade system performance. Consequently, distributed approaches are suited to the license-exempt band because the same channel can be used by other systems.

Immediate monitoring of variations in channel conditions is more effective than attempting to control the resources. For the licensed spectrum, the centralized approach is recommended simply because it has better performance. In the next two subsections, we present the proposed centralized and distributed channel assignment schemes for WiMAX MMR and WiFi mesh networks.

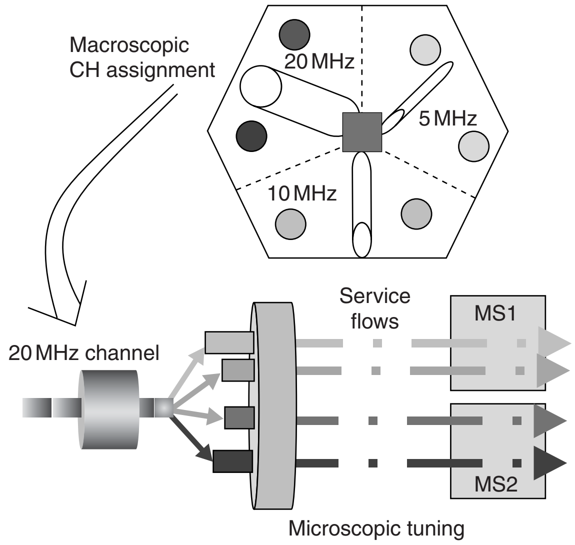

Figure 4
Two levels of channel assignment scheme.

3.2 Centralized channel assignment in WiMAX MMR networks

The proposed centralized channel assignment in WiMAX MMR networks is executed at the controller (i.e., the portal node). Periodically, each BS or RS sends a summary of its traffic load to the controller, including the traffic load of each link. Then, the controller conducts TE by allocating resources to each BS and RS at two levels (**Figure 4**). At the top level of macroscopic CH assignment, one channel with a suitable channel size is allocated to each station (for an omni-directional antenna) or each sector (for a directional antenna). Scalable OFDMA (SOFDMA), which is the default PHY in WiMAX MMR, allows a scalable channel size of 1.25, 5, 10, or 20 MHz. At the lower level of microscopic tuning, each BS or RS individually determines the number of subchannels and time slots allocated to its RS or mobile stations (MSs) in both the frequency and time domains.

To achieve interference-free communications in MMR networks, each controller needs to consider the interferences within and outside its control region. After computing the results of channel assignment, a controller distributes them to the BSs and RSs under its control and also sends a report to the controllers of adjacent regions.

3.3 Distributed channel assignment in WiFi mesh networks

Because the WiFi networks are operated in the license-exempt band, which is shared by many wireless systems and many users, interference could come from within the system and also from other systems. It is impossible to guarantee absolute control of radio resources without modifying the 802.11 MAC protocol. Therefore, a distributed approach in which each mesh node determines its channels based on the local information and adjusts to the channel conditions faster is preferable. Similar to channel assignment in MMR, we propose a two-level channel assignment and utilization scheme to achieve TE in 802.11 mesh networks. The top level deals with a load-balanced QoS-aware channel assignment aiming to minimize the bandwidth usage variance among the wireless channels. The bottom level, on the other hand, allocates channel utilization within the same channel by adjusting the Transmission Opportunity (TXOP)[note 1)] value.

3.4 Load-balanced channel assignment in 802.11 mesh networks

The main goal of the channel assignment process is to balance the loads of different channels across the network. This can be achieved by minimizing the channel usage variance within the network. The estimation of channel usage is based on the traffic load (TL), amount of traffic on a link, and loss ratio (LR), which is the ratio of unsuccessful to successful transmissions, of links that are tuned to the same channel and are within the interference range. First, the TL of a virtual link between any two nodes within communication range is measured at the routing layer, including routing control data such as HELLO and topology control (TC) packets in Optimal Link State Routing (OLSR),[note 2)] traffic originating from the transport layer of the measuring node, and data traffic from neighboring nodes that needs to be forwarded. The expected outgoing traffic demand for one node to a virtual link is expressed as:

$$TL(1.0+LR). \tag{1}$$

By considering the traffic load in both directions, the total expected traffic load on a virtual link connecting nodes a and b is represented as:

$$TL_a(1.0+LR_a)+TL_b(1.0+LR_b). \tag{2}$$

Next, the usage of a channel in a node's neighborhood is considered to be the total traffic load of the links tuned to the same channel within its interference range. The virtual links within this area that are tuned to the same channel are said to belong to the same contention set (CS). In particular, the contention set centered at node n that is sharing channel c is denoted as $CS_{n,c}$. To calculate the expected traffic load of the virtual links within the contention set, each node distributes a TC message carrying its TL and LR information, along with the current channel assignment, to the nodes within the local area. The Expected Channel Usage (ECU) for each channel c in the local area centered at node n is computed using the collected TL and LR values. The traffic demand values can be scaled by bandwidth BW to allow a more accurate comparison between links of varying capacities. $ECU_{n,c}$ is expressed as:

$$ECU_{n,c}=\sum_{i=1}^{S}\frac{TL_i(1+LR_i)}{BW_i}\ , \tag{3}$$

where S equals the number of links that can be found within a contention set $CS_{n,c}$.

We propose an intelligent heuristic to find the largest variance decrement in the local area. The problem of finding an interface and assigning its channel from c_1 to c_2 to achieve the maximum variance decrement can be expressed as:

$$\max_n\,[\max_{c_1,c_2}(VAR_n^{old}-VAR_n^{new})], \tag{4}$$

where VAR_n is the variance of ECU across the set of available channels C in the local area centered at node n.

The part within the brace can be simplified as:

$$\begin{aligned}&\frac{2}{C}\max_{c_1,c_2}\left[X(ECU_{n,c_1}^{old}-ECU_{n,c_2}^{old}-X)\right]\\&\leq\frac{1}{2C}\max_{c_1,c_2}\left[(ECU_{n,c_1}^{old}-ECU_{n,c_2}^{old})^2\right],\end{aligned} \tag{5}$$

where $X=ECU_{n,c_1}^{old}-ECU_{n,c_1}^{new}=ECU_{n,c_2}^{new}-ECU_{n,c_2}^{old}$ is the amount of channel usage shifted from c_1 to c_2 and the equality happens when $X=(ECU_{n,c_1}^{old}-ECU_{n,c_2}^{old})/2$, which is called the ideal shift load. Therefore, using this method, each node attempts to equalize the channel usage by retuning the interface currently on the channel that has the greatest usage to the one that has the least usage. The amount of traffic load on the links using this interface is the actual shift load, denoted as δ.

note 1) In particular, TXOP here represents the maximum duration of a single transmission a node is allowed to send.

note 2) The proposed channel assignment scheme can be generalized to work with any routing protocol.

Because δ becomes closer to X, the variance decrement in the local area increases. The interface with the smallest difference between δ and X is chosen as the interface to be retuned to the least-used channel.

3.5 Control channel utilization within single channel in 802.11 mesh networks[13)]

Due to the limited granularity in the number of channels in IEEE 802.11 systems (3 and 12 channels in the 2.4 and 5.8 GHz band), a channel is usually shared by many stations within the interference range. The goal of this step is to control the channel utilization of all stations sharing the same channel in a fair manner based on their traffic demands. We propose a two-step approach to achieve the goal of traffic engineering. In the first step, given the input of the traffic matrix, the problem of routing and link bandwidth assignment is formulated as a linear programming problem. Next, we adjust the TXOP, which is a parameter of Enhanced Distributed Channel Access (EDCA) in the 802.11e standards,[12)] such that the link throughput approximates the desirable link load computed from the first step. The cases of single-hop and multi-hop networks are both considered. Details of the procedure can be found in Reference 13).

4. P2P mobility management

Integration of heterogeneous systems and provision of resilient wireless networks enable users to access Internet more conveniently. Several standardization groups have been working towards this goal, including UMA, IEEE 802.21 media independent handover (MIH), and IETF MIPv6 Signaling and Handoff Optimization (mipshop). However, there is still a long way to go before standards are adopted and implemented by network operators. As we indicated in Section 1, P2P technologies enable end users to construct overlay networks to conduct various tasks without support from the infrastructure. Great potential exists for applying P2P to achieve goals in FMC. Limited mobility is supported in existing P2P applications. For instance, Skype utilizes a decentralized user directory to associate the static user ID with the user's IP address. The end-system-based mobility management scheme for IPv6 described in Reference 14) achieves a similar goal. Nevertheless, the functions of session continuity and seamless handover have not been explored in current P2P applications. We are currently studying the functionalities of Mobile IP (MIP) and 802.21 MIH operating in a P2P manner to realize, respectively, session continuity and seamless handover. MIP[15),16)] supports transparency above the IP layer and realizes session continuity, but home agents (HA) and foreign agents (FA) are required in the networks. Similarly, 802.21 enables MIH seamless handover but relies on some functionalities implemented on the infrastructure side. The power of P2P is that it moves the essential functionalities to the end systems. Such a pattern has been seen in many emerging applications. For example, recently a startup company called FON advocated the idea of bandwidth sharing by implementing P2P software on the users' WLAN routers. By following a similar deployment strategy, the functions of MIP and MIH can be implemented in a P2P program and adopted in the following three scenarios (**Figure 5**).

1) Users install the program on their own

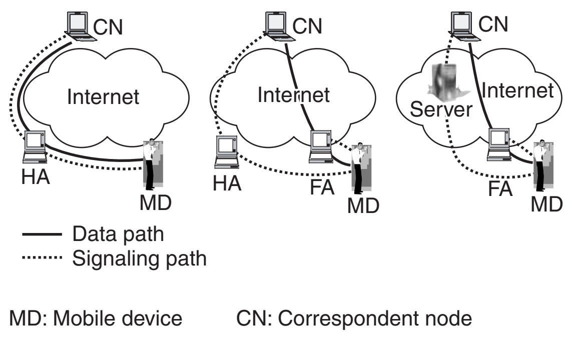

Figure 5
Three scenarios of P2P mobility support.

computers as their HAs and MIH servers but do not share resources with each other. The same program is installed in the users' mobile devices (MDs), but only the MIP and MIH client modules are enabled. Traffic from other correspondent nodes (CNs) is always through their HAs to MDs. Moreover, MIH modules in MDs with more than one type of network access ability can create two connections at the same time by maintaining two entries in the users' MIH servers so that make-before-break handover is feasible. That is, zero handover latency can be achieved. The main drawback of this approach is the inefficiency of the triangular route that is used.

2) Users share resources with each other and make their own HAs and MIH servers accessible by other peers so they serve as FAs for the visitors. The MIH functions in this case can reside in the HAs and FAs. This scenario not only shares computation power but also network access.

3) If users do not have their own HAs and cannot provide resources to other peers, they will need to ask a server to function as an HA and will be charged accordingly by the service provider.

Among these three scenarios, scenario 1) requires the least infrastructure support and therefore is the most generic overlay networking solution for P2P applications. Solutions based on scenarios 2) and 3) require more support functions from service providers, which on the other hand enables network resource sharing among peers and offers the potential for improved resource usage. In other words, we can expect scenario 1) to provide purely distributed mobility support in the style of overlay networking. On the other hand, for the QoS management of scenario 1), even when we assume an integrated WiFi/WiMAX service and its QoS management at Layer 2 and below as described in Sections 2 and 3, management of P2P application QoS will be subject to the positions of HAs, which will make its QoS less controllable.

This style of management of scenario 1), which utilizes a purely distributed overlay network architecture, realizes its flexibility by decoupling itself from the underlying network infrastructure. On the other hand, it involves inefficient network resource usage, and we can observe that architecture flexibility and network resource usage efficiency are two sides of the same coin in scenario 1). As the P2P community grows and the network resource usage efficiency becomes more important, there should be a gradual evolution from scenario 1) to scenario 2) then 3). When this architecture convergence occurs, QoS management of P2P services will also be integrated with that of the wireless link layers — in the same way thatWiFi and WiMAX networks will be integrated as described in Section 2 and 3. When the three scenarios fully converge to scenario 3), we will see P2P services and their management become subsumed into NGNs as part of their infrastructure and the achievement of full FMC.

5. Conclusion

We have studied and observed that FMC, which enables complete portability of wireless and wired services and applications over networks using portable devices, can be achieved both by NGNs and P2P, with the additional consideration of MIP and MIH support. There appears to be a competition between the two, but in reality NGNs will provide a better service environment for realizing P2P services than is available today.

Seemingly, P2P provides an alternative paradigm to NGNs for FMC, which allows a new overlay service to be built without a massive infrastructure investment. The P2P paradigm provides the intriguing possibility of a more scalable, pay-as-you-go type approach for management architecture, which is probably more suitable for new, unproven, and often unaccountable Internet applications. The P2P paradigm also seems effective when the availability of network resources is not always guaranteed, as is often the case in WiFi-based ad-hoc networks.

NGNs, therefore, will benefit by incorporating the P2P paradigm in their architecture principle to complement their backbone architecture as part of its scalable extension to cover applications and services not fully accommodated by the NGN backbone architecture. As we observed in Section 4, architecture flexibility and network resource usage efficiency are two sides of the same coin in P2P, and as FMC progresses we expect that many present-day P2P services will gradually converge into NGNs.

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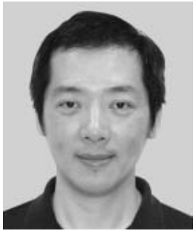
Wei-Peng Chen, *Fujitsu Laboratories of America*
Mr. Chen received the B.S. degree in Electrical Engineering from National Taiwan University in 1994, M.S. degrees in Electrical Engineering from National Taiwan University and Ohio State University, in 1996 and 2001, respectively, and the Ph.D. in Computer Science from the University of Illinois at Urbana-Champaign in 2004. Since September 2004, he has been a research staff member at Fujitsu Laboratories of America, focusing on research topics in the areas of wireless mesh networks, medium independent handover systems, PoC performance evaluation in 3G networks, data traffic analysis, modeling, simulation for ubiquitous communications, and software-defined radio and cognitive radio. He is a member of the IEEE.

Takeo Hamada, *Fujitsu Laboratories of America*
Mr. Hamada received the B.E. and M.E. degrees in Electrical Engineering from the University of Tokyo in 1984 and 1986, respectively. He joined Fujitsu Laboratories in 1986. After receiving the Ph.D. in Computer Science from the University of California San Diego in 1992 in the field of physical VLSI design, he joined the telecommunications research group at Fujitsu Laboratories in Kanagawa, Japan. He spent 1995-1997 at Bellcore in Red Bank, NJ, as a part of the TINA core-team, working on various management architectures of TINA, such as accounting, security, and service management. Since 1998, he has worked at Fujitsu Laboratories of America, where he has been engaged in the study of Internet traffic and its management, optical networking and its control plane architecture for multi-layer, integrated data-optical networking.



Jason Jeyhsin Yao, *National Taiwan University*
Dr. Yao received the B.S. degree in Electrical Engineering from National Taiwan University in 1984, and the Ph.D. in Electrical and Computer Engineering from the University of California, Santa Barbara in 1992. He has worked for AT&T Bell Laboratories, Fujitsu Network Transport Systems, and Fujitsu Laboratories of America. Dr. Yao is currently a visiting scholar at National Taiwan University in Taipei where he is engaged in research on multimedia streaming over P2P networks, Internet Protocol TV, digital video broadcasting, and issues involving high frequency circuit design. Dr. Yao has published extensively on his research topics, and also holds an MBA from Santa Clara University.

Hung-Yu Wei, *National Taiwan University*
Mr. Wei received the B.S. degree in Electrical Engineering from National Taiwan University in 1999. He also received the M.S. degree and Ph.D. in Electrical Engineering from Columbia University in 2001 and 2005, respectively. He was a summer intern at Telcordia Applied Research in 2000 and 2001. He was with NEC Labs America from 2003 to 2005. He has been an Assistant Professor in the Department of Electrical Engineering at National Taiwan University since July 2005. His research interests include wireless mesh networks, mobility management protocols, cross-layer design and optimization in wireless multimedia communications, and game theoretical models for communications networks.