Broadband Convergence Network (BcN) and Associated Technologies

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- Heterogeneous NGMN Architecture and Interoperability
- Standards Toward Broadband Wireless Internet
- Mobile Broadband Wireless Access
- Network Selection and Handoff Techniques
- Closing Remarks
Today’s Communications World

- Wired networks, e.g. Ethernet, broadband Internet, ADSL, Fiber, ...
- Wireless networks
  - GSM, UMTS
  - cdmaOne, cdma2000
  - WLAN
  - WiMAX, MobileFi, ...
  - Broadband satellite
- Broadcast terrestrial and satellite networks, e.g. DAB, DVB, ...
Wireless Network Development

Cellular Phones
- 1981: NMT 450
- 1986: NMT 900
- 1992: GSM
- 1994: DCS 1800
- 2000: GPRS
- 2001: IMT-2000

Satellites
- 1962: Inmarsat-A
- 1988: Inmarsat-C
- 1992: Inmarsat-B
- 1998: Iridium

Cordless Phones
- 1982: Inmarsat-A
- 1984: CT1
- 1985: CT0
- 1986: CT1
- 1987: CT+1
- 1991: DECT

Wireless LAN/MAN /WAN
- 1980: CT0
- 1984: CT1
- 1987: CT+1
- 1991: DECT

- 1997: IEEE 802.11
- 1999: 802.11a, Bluetooth
- 2000: IEEE 802.11a
- IEEE 802.11g/e/n
- 2007: Fourth Generation (Internet based?)

Application Growth

- Significant increase in number of subscribers, more felt toward mobile and data applications

![Graph showing application growth from 1998 to 2005](image-url)
Progression of Communications

Analog (1G)  \rightarrow  GSM, cdmaone (2G)  \rightarrow  GPRS (2.5G)  \rightarrow  UMTS, cdma2000 (3G)  \rightarrow  ?

WLAN 802.11a/b  \rightarrow  WLAN 802.11g  \rightarrow  WLAN 802.11n  \rightarrow  ?

Parallel Progress OR Converging?

Heterogeneity of Mobile Networks

- Networks differ based on
  - Air interface and spectrum requirements
  - Offered services
  - Data rates and QoS requirements
  - Modulation and coding scheme
  - Core network functionalities
  - Signaling requirements between terminal and network etc.

- Service across other networks is not guaranteed
  - Lack of interoperability
  - Lack of service agreement

- Users require
  - Different handheld terminals
  - Separate subscriptions
Next Generation Mobile Network

- To offer an integrated system
- To promote interoperability among networks
- To offer global coverage and seamless mobility
- To use the same handheld terminal
- To enhance service quality compared to current wired networks

ITU Recommendations
- Open system
- Access-independent underlying transport technology (IP based)
- Access-independent service oriented functionalities
- Seamless mobility across networks
- Better end-to-end service quality

NGMN System Model

- Architecture supporting heterogeneous networks
- Adaptive protocol stack
- Enhanced mobility management addressing different handoffs
- Enhanced resource management to admit horizontal and vertical handoffs

Open Design Issues
- Adaptive NGMN Architecture
- Cross-layer coordination
- Vertical handoff
- Call admission control (CAC)
- Mobile terminal
BcN

- Broadband Convergence Network is a step beyond the NGMN
  - Integration of heterogeneous fixed and mobile networks with varying transmission characteristics

Inter-Domain Service

- Services transit from fixed domain into mobile domain and vice versa *seamlessly*
- No sensible change of service quality received by a user while moving from a fixed domain into a mobile domain
  - Fixed-to-mobile or mobile-to-fix domain
  - From one mobile network to another mobile network
- Service independency to the radio access technology
  - No dramatic change in QoS particularly in data rate (i.e., the most humanly sensible quality measure)
  - Logically followed by the delay requirement
- Such service availability will need modifications at all layers of the network protocol stack
- A system of authentication and authorization that supports access across different network is also needed
Protocols Re-Design

- Physical layer
  - Multiple physical network interfaces (cellular, W-LAN, ...)
- Link layer
  - Establishment of concurrent connections via different access networks
  - Packet scheduling and optimum network selection
- Network layer
  - Accommodating mobility in IP protocol
  - Faster and easier routing techniques with less signaling
  - IP global (and heterogeneous) address translations
- Transport layer
  - More wireless friendly TCP and UDP type protocols
- Application layer
  - Management of optimum compression and data rate control

Heterogeneous NGMN Architecture and Interoperability

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Motivations behind NGMN Designs

- Emergence of several access technologies has resulted in a multitude of heterogeneous systems targeting different service types, data rates, and users
  - 1G to 2G migration: A transition from analog to digital
  - 2G to 3G evolution: Popularity of Internet and need for higher mobile data rates
  - Complementing service from several access technologies:
    - Cellular: 2G (GSM and IS-95), 3G (UMTS and cdma2000)
    - High speed data networks: IEEE 802.11, HiperLAN
    - Digital broadcasting systems: DAB, DVB, DMB

- The missing bit
  - A single architecture to integrate all these and future systems, enabling users to have global reliable connectivity

Main Motivations

- Demand for better availability of services and applications
- Global connectivity for any-type services at anytime, anywhere and anyhow
- Rapid increase in the number of wireless subscribers who want to make use of the same handheld terminal while roaming
- Support for bandwidth intensive applications such as real-time multimedia, online games and videoconferencing as well as traditional voice service (e.g., through VoIP)
- The scalable and distributed next generation mobile network architecture is expected to offer any-type services over a diverse set of indoor, outdoor, pedestrian, and vehicular
- These services will be offered over a large range of overlapping access networks that offer different data rates, coverage, bandwidth, delay and loss, and other QoS requirements
Universal Ubiquitous Coverage

- Universal ubiquitous coverage across different radio technologies is the ultimate objective of the future mobile networks
  - Answering the increasing demand for higher transmission rates and flexible access to diverse services
  - Offering a rich range of services with variable bandwidth and quality
  - Satisfying users’ mobility and traffic service requirements
  - Covering different geographic areas and accessing to different types of service
- The universal ubiquitous coverage need to be realized through
  - Connectivity across multiple networks
  - Interoperability across different radio technologies

IP-based NGMN

![Diagram of IP-based NGMN](image)
Key Features

- Mobile terminals will be able to auto-configure to the specific access technology at the location of the terminal.
- Subscribers will have access to the various services on offer and enjoy a wired network equivalent quality of service, cost and security, even while running real-time applications.
- Ubiquitous and seamless connectivity will be provided through effective mobility, resource and QoS management schemes.
- The investments made by the subscriber will be respected by limiting the changes required in the multi-access mobile terminal in terms of hardware or software.
Key Research Objectives

*Toward a harmonized heterogeneous NGMN*

- Integration of all existing and future communication access systems through a common IPv6 (Internet Protocol Version 6) gluing mechanism
- Development of a modular and scalable architecture with well-defined distributed network functionalities
- Development of effective mobility, resource and QoS management schemes to offer seamless connectivity and end-to-end QoS between peer end terminals
- Development of physical architecture of a QoS enabled mobile terminal capable of accessing the Internet and real-time services over a multitude of access technologies
- Offering similar services (subject to network capacity and service policy) in both home and visited network based on preferences and service agreement in the subscription

Network Heterogeneity

- Heterogeneous environment means
  - Different data rates at physical layer
  - Different physical layer characteristics (BER, congestion, ...)
  - Different mobility management due to different size of cells (less handoff versus higher data rate)

- The next generation mobile network is expected to face two main constraints:
  - Heterogeneity in physical access network
  - Change of applications from commonly low data rates into more bandwidth demanding real-time and multimedia ones

- Then
  - How to achieve guaranteed QoS?
  - How to effectively manage network resource and security?
A Typical Mobility Scenario

IPv6 Core Network

User in a vehicle running a real-time video application

NGMN Research Projects

- The NGMN proposals in the literature are mainly looking at three major internetworking elements:
  - Mobility management
  - Resources management
  - QoS management

Some Examples
- IST project of Mobility and Differentiated Services in a Future IP Network (Moby Dick)
- Multimedia Integrated Network by Radio Access Innovation (MIRAI)
- NTT DoCoMo’s MAGIC
- Designing Advanced network Interfaces for the Delivery
Mobility Management

- Managing terminal mobility - where the MT moves within and across network domains while continuing to receive access to the services without any data packet loss and with minimum handover delay
- Managing personal mobility - where the subscriber obtains services in a transparent manner within any network and on any terminal, on the basis of subscriber identification and network ability to provide the concerned services

Key issues
- How to address both fast and slow moving subscribers?
- How to solve intra-Access Router, inter-Access Router, and inter-domain handover encompassing both horizontal and vertical handover?
- How to solve the need for the mobile terminal to scan all possible access technologies for wireless system discovery with limited battery power?
- How to reduce the signaling load when the mobile terminal experiences frequent handover across smaller cells?

Resource Management

- Provision of adequate resources within access and core network to support communication sessions
  - Capability to offer services to roaming subscribers similar to the home network environment (subject to visited network capability and services) upon subscriber authentication
  - Management of local resources independent of roaming subscriber's home network
  - Allocation of adequate resources required by end terminal applications before the commencement of a communication session and possible re-negotiation during the session

Key issues
- How to ensure that resources, as required by the end terminal application, can be offered between peer end terminals?
- How to make sure that resource allocation takes into consideration current network conditions?
- How to provide secure communication path between neighboring resource management entities, independent of actual data communication path?
QoS Management

- Ensuring QoS support to a wide range of services over dynamic link conditions
  - Capability to set up data path and negotiate QoS between peer end terminals at the commencement of a session, and dynamic renegotiation to sustain data transfer during the session
    - QoS parameters that influence the negotiation include available bandwidth, data rate, user preferences, end terminal capacity and application requirements
  - Distributed architecture that supports differentiated services, as per the service policy and type of subscription

- Key issues
  - How to ensure end-to-end QoS between peer end terminals?
  - How to maintain QoS for an ongoing application session with degradation of link quality?
  - How to offer differentiated services across access and core network based on subscriber profile and service policy?

Mobility Management

- Two forms of mobility during seamless connectivity across heterogeneous networks:
  - Macro-mobility - mobility across different sub-networks (between HN and VN)
  - Micro-mobility - mobility across different access points within the same sub-network (within HN or VN)
- Mobile IP - a solution to macro-mobility, originally developed for wired networks
  - Using the concepts of HA, FA, CoA, CN
  - Stateless or stateful auto-configuration and triangular route optimization
  - Offering a transparent, simple and scalable global mobility
  - More recent works to include micro-mobility in wireless environment (still the latency and signaling are issues)
    - Also further aggravated with varying link conditions, higher subscriber mobility and scarcity of resources

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MM in Moby Dick

- Proposes an architecture that offers E2E QoS and seamless mobility across heterogeneous networks
  - Mobile end terminals, equipped with interfaces of W-CDMA (UMTS-TDD), WLAN (802.11b), and Ethernet, access the Internet through Access Routers (ARs) that provide interfaces between wireless access network and wired core network
  - The network management entities such as QoS Brokers, AAAC servers, and Paging Agents are located in the fixed core network
  - Adopts Fast Handovers for Mobile IPv6 (FMIPv6) which increases the frequency of Binding Update (BU) to a distant Home Agent (HA) and a Correspondent Node (CN) after every migration to a new access point
    - Resulting in a considerable increase of signaling overhead, especially with a high concentration of subscriber base in urban areas

source: http://www.ist-mobydick.org/
Problems with MM in Moby Dick

- Access to services across various administrative domains and different access technologies is provided according to the subscriber preferences stored in a profile at HN.
- FMIPv6 fails to eliminate handover latency completely.
- After every successful handover and after attaching to the new AR, the MT is required to send BU to both HA and CN.
- In future systems with overlapping heterogeneous networks, MT is required to scan over all terminal interfaces to find out available resources, determine whether a handover is imminent, select the target AR, and initiate a handover request to the current serving AR.
  - Significant processing power required to listen to all broadcasts over different access technologies and select target AR after gathering required Layer 2 information.

MM in MIRAI Architecture

- Uses a hierarchical structure comprising of Base Stations (BSs), ARs within the common core network (CCN), and the Gateway Router (GR) connected directly to the Internet.

- The Signaling Agent (SA), the key element in the architecture, is located on the same level as ARs and maintains two databases namely Location Database (LDB) and Resource Database (RDB) for controlling the data transmission process within the domain.

- The dedicated network known as Basic Access Network (BAN) provides paging, wireless system discovery and mobility management for Multiservice User Terminal (MUT) through a common control/signaling channel.

Problems with MIRAI Architecture

- During initial registration, a roaming MUT determines its exact location using a Global Positioning System (GPS) receiver embedded in the terminal and sends the information (e.g. latitude, longitude, altitude etc.) to the network over the BAN to facilitate location management and service optimization.
  - GPS signaling is severely undermined within indoor environments, or by the presence of thick foliage.
  - The MUT generates local CoA through stateless IPv6 auto-configuration (from the domain subnet prefix broadcast over the BAN system). Usually the generation of a local CoA by stateless IPv6 auto-configuration from subnet prefix ID is accompanied by a Duplicate Address Detection (DAD) to determine the uniqueness of the CoA.
    - It is extremely difficult to run DAD in a wireless environment, and without a DAD the generated CoA runs the risk of being a duplicate within the domain causing service disruption.
  - MIRAI suffers from the absence of a definitive QoS enabled MUT terminal with cross-layer coordination and an effective QoS and resource management scheme.
Augmented Mobility Management

- Use of Fast handover for Hierarchical Mobile IPv6 (FHMIPv6) instead of FMIPv6 used in Moby Dick to considerably reduce the handover latency
- Using a dedicated control/signaling BAN system, independent from the existing heterogeneous access networks (unlike the overlaid BAN architecture in MIRAI)
  - wireless system discovery and paging services
  - location management
  - support for vertical handover
  - simplicity and energy reserving capability
- All overlapping heterogeneous networks within the domain access the Internet through the Mobility Anchor Point (MAP)


Augmented Mobility Management

- The Gateway (GW) connects multiple MAPs to offer faster connectivity and data transfer during inter-domain handovers
- Every domain is maintained by an administrative body and service agreement exists among different access technology providers
- Identifying a roaming MT by three IP addresses:
  - MT’s home address
  - MAP’s IP address or regional care-of-address (RCoA)
  - A local CoA (LCoA) assigned by DHCPv6 enabled AR
- BAN periodically broadcasts a list of available access technologies within the coverage area and their services on its reliable low data rate channel
Hierarchical MM Architecture

Augmented Mobility Management

- Three possible types of handovers:
  - inter-BS
  - inter-AR
  - inter-MAP

- Example: A roaming terminal “M” linked to AR2 has an ongoing session with a terminal “N” linked to AR3 in a different domain. As the MT leaves its serving domain, it initiates an inter-MAP handover, that includes:
  1. RAN list broadcast and reply to ascertain availability
  2. handover trigger and request by MT
  3. resource negotiation by GW with MAP2, AR3 pair in the target domain
  4. bi-casting of data packets to both MAP1 and MAP2 by GW
  5. MT registration with AR3 to re-establish data session
  6. GW then sends a request to MAP1 to release connection. In the absence of such a request, a timeout period applies
Complimentary Functions

- Interoperable networks provide complimentary function to one another
  - Better mobility and portability management
    - PAN, LAN, MAN, WAN: from no mobility to global mobility
    - Device portability from less portable to more portable
  - Higher throughput and bit rates
    - File downloading versus web browsing or real-time streaming
  - Lower delay
    - Voice quality requirement versus delay insensitive data
  - Higher reliability and availability
    - Customer-based telephone network with essential reliability and availability versus the IP ‘best effort service’
  - Better power management and lower power consumption

Two-Dimensional Interoperability

- Global Coverage
- Cellular Wide Coverage
- Local WLAN Coverage
- Personal B/T, UWB Coverage
Interoperability – Components

- Inter-network mobility
  - Network layer seamless mobility for fast and lossless intersystem handovers
  - IP connectivity and inter-network traffic load optimization

- AAA architecture
  - Advanced security and billing techniques for a multi-network, multi-operator environment

- Reconfiguration
  - Link layer adaptive algorithms to match different propagation and channel error conditions

- QoS negotiation and adaptation
  - QoS mapping and service adaptability during handover from one network to another (maybe a different) network

Interoperability – User Parameters

- Terminal type
  - Depending on user terminal capabilities (PDA, laptop, cellular phone), one or more networks would have a higher priority than others

- Traffic type
  - Depending on the type of application traffic (real-time vs. non-real-time, data vs. voice, etc.), one or more networks would be a better choice as the transport network

- Service tariffs and service availability
  - The cost associated for each service will depend on network type (e.g., WLAN versus cellular), which has immediate impact on user’s network preference
Layered NGMN Architecture

Third party applications and value added services
Service control and mechanism essential for the smooth operation of the network architecture
Access independent network functionalities in a transparent manner hiding access specific signaling requirements
Access network interfaces, connecting reconfigurable SDR-based end terminals

Detailed Layered NGMN Architecture

Application Level
Third party applications

Network Level
Service control and mechanism essential for the smooth operation of the network architecture

Convergence Level
Access independent network functionalities in a transparent manner hiding access specific signaling requirements

Physical Level
Access network interfaces, connecting reconfigurable SDR-based end terminals
Layer Functions

- Application - This layer comprises of the third party applications provided to the subscribers. Third party refers to applications provided by someone independent of the network operator.

- Network – This layer provides service control and mechanism essential for the smooth operation of the network architecture. Acting as the linchpin, this layer provides management of services and dynamic cross-layer coordination between different layers to facilitate enhanced operation.

- Physical – This layer consists of core network and heterogeneous access networks. Reconfigurable Software Defined Radio (SDR) based end terminals are required to support multimode services across a wide range of radio access networks (RANs).

Network Sub-Layers

- Services: User profile, location server and AAA server within this sub-layer provide the repository for user preferences, dynamic information associated with the subscriber, terminal and service mobility, subscriber identity authentication and charging information associated with the resource usage during user activity
  - repositories are located both in the home network and the visited network

- Mobility management: Consists of functions to enable subscribers with the ability to move between IP sub-networks; supports: location update of a dormant or roaming subscriber, wireless system discovery and selection to initiate and sustain a communication session, optimize the routing path between peer end terminals, seamless mobility with no packet loss and minimum handover latency
  - located within the serving domain to reduce signaling overhead during handover period
Network Sub-Layers

- Resource Management: Manages IP addresses of roaming and home subscribers, initiates fast context transfer (e.g., user profile, QoS parameters etc.) between access networks as the subscriber changes its point of attachment, and controls the resources within the domain through Bandwidth Manager
  - located in home, visited and all intermediate networks
- Bandwidth Manager: Offers functionality regarding new call admission and support of existing sessions, session and service enforcement policy (e.g., expected QoS, valid times, routes etc.) and allocation and de-allocation of resources before and after a session between peer end terminals
- QoS Management: Offers E2E QoS service between peer end terminals through optimal path establishment and possible re-routing owing to link quality degradation; also effective traffic and flow control to eliminate bottlenecks especially in access networks, offering differentiated services
  - located in home, visited and all intermediate networks

Security and OAM&P

- Spanning the entire layered architecture and involves the following functionalities
  - Ensures authorized use of network resources and services by subscribers, confidentiality and non-repudiation of services and resources
  - Maintenance of all three layers (application, network, physical) during the lifespan of a communication session
  - Fault management when experiencing sudden breakdown of a link or a functional entity
  - Performance management to ensure user requested QoS can be supported
  - Billing management in accordance to the real-time and non-real-time resource utilization during subscriber activity
  - Policy management to enforce functionality conforming to service policy and subscriber preferences

(OAM&P: Operation, administration, maintenance, and provisioning)
IP Architecture

- If we agree on the assumption that IP will be the core part of the next generation mobile networks, then the traditional protocol architecture seems to be inadequate
  - A modular architecture designed based on stack of protocols
    - Using services provided by the lower module
    - Providing new services to the upper layers
    - Communications mainly between adjacent layers

IP Architecture – Conventional

- Link layer (e.g. Ethernet): Providing connectivity to other network segments; i.e. not to hosts in different networks
- Network layer (e.g. IP): Delivering datagram packets across multiple networks
- Transport layer
  - TCP: Providing connection-oriented communication services, making communication reliable, avoiding network congestion
  - UDP: Providing simple and unreliable transport for quicker communications (required for real-time applications)
- Where to put the main elements necessary for NGMN?
  - QoS: So that IP network could be used for voice, video, and other multimedia real-time services
  - Mobility: Among APs of the same technology (micro-mobility) or across networks of different technologies (macro-mobility)
IP Architecture – Modified

- Adding mobility features at network layer
- Increasing address space and easing routing at IP layer
- Modifying TCP for better performance at high error rate environments (e.g. over wireless channel)
- Additional sub-layers for adaptive selection of a network and associated MAC protocol

![Protocol Architecture Diagram](image)

Protocol Stack Enhancement

- Modifications of individual layer protocols so that the overall architecture can handle the heterogeneity
  - E.g., proposal of AdaptNet


- Modification of overall protocol stack, removing the modularity character from it and allowing interaction of protocol layers with layers other than the adjacent one
  - The Cross-Layer architecture design

AdaptNet

- Making link, transport, and application layers adaptive (not changing the network layer) at mobile host
- Also inclusion of some cross-layer interactions
- Application layer
  - Handling data and bit error rate fluctuations of the wireless channel by means of adaptive source and channel coding
- Transport layer
  - Use of an adaptive mobile-host-centric transport protocol called Radial Reception Control Protocol
- Link layer
  - Use of an adaptive MAC for seamless medium access control over heterogeneous networks
  - Use of an adaptive error correction scheme which changes the coding rate in accordance with the channel condition

AdaptNet

- Concept of the adaptive application layer
  - For the mobile video (conversational and streaming), the heterogeneity of the network (thus different data rates) as well as the wireless time- and location-dependent rate and loss, makes serious problems for picture quality, that could propagate to future frames too
    - Solution: Terminals adaptively adjust the video bit rate
  - Transport layer monitors the channel conditions and pass them to application layer
  - A joint optimization of source and channel code rates
    - FEC code rate for each packet and transcoding parameters for each frame are optimized to maximize the expected video quality at the client
    - The channel information helps in making a better decision in adjusting the coding parameters, and to reduce delays of important video packets
AdaptNet

- Concept of the adaptive transport layer
  - Operating on a mobile-host-centric way
    - Control of connection congestion at the mobile host
    - Change of server or number of simultaneous interfaces
  - Maintaining multiple states
    - To minimize the impact of handoff latency as well as handling packet reordering and loss recovery during handoff
  - Adaptive congestion control
    - Monitoring the wireless random loss rate and delay and adjusting the congestion control adaptation parameters for heterogeneous networks

Cross-Layer Architecture Design

- Concept: By leaving protocol stack strictly modular, it will be inefficient with respect to performance, QoS, and energy consumption, etc.
- Solution: Proving information from non-adjacent layers in a cross-layer structure
Coordination Planes

- Four separate *vertical planes* that coordinate the information exchange and actions to be done by individual layer protocols

- **QoS**: For distribution of QoS requirements and constraints and coordination of efforts by layers to achieve QoS

- **Security**: For elimination of encryption duplication at several layers

- **Mobility**: Enhancing interactions among TCP, IP, and link layers in handling mobility in different environments

- **Wireless Link Adaptation**: Providing adaptive bit error rate and data rate depending on different wireless channel conditions and different mobile environment

Quality of Service

- Effective QoS provisioning for simultaneous use of multi-service so that low priority traffics do not negatively impact on more sensitive traffics
  - QoS has to be treated on an end-to-end basis
  - QoS must be handled by all communication layers

- As an example, for a real-time video conferencing service, currently only transport layer by the means of RTP handles the QoS
  - An effective coordination between link and transport layer can significantly improve the QoS provisioning
  - One example is to coordinate ARQ to avoid extra delays

- Transmission power can be adjusted too in conjunction with delay, BER, and bit rate variations of wireless channel
Security

- Added processing power, energy consumption, and delay due to multiple layers that are performing encryption
  - Transport/application layer; e.g. SSH, SSL, and PGP
  - Network layer; e.g. IPSec, DiffServ, and IntServ
  - Link/physical layer; e.g. WEP in IEEE 802.11, Bluetooth, and mobile terminal-serving network data and signaling encryption in GSM/UMTS cellular systems, AAA
- The individual higher layer security schemes are either between applications or between hosts
- Link layer techniques are either insecure (WEP) or have local scope
- A coordinated scheme could secure the system more efficiently, especially in a heterogeneous environment

Mobility

- The traditional IP network was not designed to handle mobility of hosts
  - TCP: After moving the host loses its current connection and reestablishment of a new connection requires extra delays
  - Mobile IP: To reconfigure IP addressing after handover to cope with problems of the non-mobile IP protocol
- In a heterogeneous system, where different networks have different characteristics (delay, bit rate, ...) direct information from lower layers to higher layers can improve the TCP and application layer adjustment much easier
  - Horizontal handover case (such as inter-cell handoff)
  - Vertical handover case
    - Examples: avoiding TCP slow start phase, adjustment of TCP RTO timers, retaining TCP states, ...
Wireless Link Adaptation

- Coordination among protocol layers in case of severe changes in wireless channel conditions
  - In case of high BER, coordination between ARQ that is currently included in both TCP and link layers
  - Avoiding retransmission of packet requested by both link layer ARQ and TCP ARQ for example as a result of long delay
  - Avoiding harmful ARQ action at link layer to non-TCP traffics
  - In case of simultaneous TCP and non-TCP flows, TCP always monopolizes the link layer as priority flow, while the non-TCP flow could have more stringent timing constraints. A preemptive link layer could solve this problem
  - The link layer ARQ could artificially increase the RTT value estimated by TCP - the value that controls the congestion window size and therefore the TCP throughput

Cross-Layer Coordination

- Cross-layer coordination between different entities within the architecture would be necessary in NGMN
  - For wireless system discovery to provide a list of access networks and their associated QoS parameters
  - To support QoS enabled application, direct communication between application layer and QoS sub-layer are essential
  - To provide services in a visited network based on service policy and subscriber profiles signaling between mobility management sub-layer and services sub-layer as well as between services sub-layer with resource management and QoS management sub-layer are essential
  - When service is no more possible after a vertical handover
  - Also for accounting purpose using information related to the resources used, QoS provided, time and duration of provision of network resources, etc
Cross-Layer Coordination Methods

Interlayer Signaling Pipe (ISP) Approach
- Cross-layer information (TCP/RLP related) are stored in the wireless extension header (WEH)
- Interlayer Pipe passes through all layers
- Suffers from longer processing delay

Direct Connectivity Approach
- Direct connectivity among non-adjacent layers
- Separate definition of APIs

- How controllable QoS parameters form individual layers translate into parametric quantities?
- How to optimize the decision process?

ICMP Approach
- Use of watermark based mechanisms to initiate ICMP messages whenever network conditions change
- Suffers from longer processing delay

Ad Hoc Network Approach
- Information exchange through external servers
- May not be suitable for time-critical applications
Cross-Layer Coordination Views

- Cross-layer coordination not yet standardized
- Room for contributions
- Will be key to offering enhanced services
- Mainly confined to the network level functionalities
- Therefore concentric to the network layer in the proposed system model

Standards Toward Broadband Wireless Internet

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Start of Broadband Wireless IP

- Inclusion of mobility features in basically non-mobile IP by introduction of Mobile IP and IPv6 protocols
- Use of Wireless LAN in
  - Extension of wired networks mobility and scalability
    - Economically and technically feasible for limited scale
    - Development of better security and traffic control techniques (Temporal Key Integrity Protocol – TKIP; Wi-Fi Protected Access – WPA; and eventually IEEE 802.11i)
  - Extension of cellular networks bandwidth in hotspot areas
    - Supplement low data-rate of cellular networks significantly where they are most needed
    - Boost the affordability, usefulness, competency of 3G cellular
  - Take advantage of IP-oriented W-LAN and its security improvements to close the gap between cellular and IP networks (that is, CS and PS)

Interesting point: There is a unique sweet spot for each standard, though there are some overlap at the edges
IEEE Wireless Broadband Standards

- Introduction of a new bunch of IEEE standards after the popular 802.11 W-LAN
  - IEEE 802.11 - The wireless local area networks family
    - 802.11 - W-LAN at 1 or 2 Mbps in 2.4-GHz band, FHSS/DSSS
    - 802.11a - W-LAN extension to 54 Mbps in 5-GHz band, OFDM
    - 802.11b - same as 802.11 with CCK rather than PSK modulation for support of 11 Mbps in the 2.4-GHz band (AKA Wi-Fi)
    - 802.11g - W-LAN for 20+ Mbps in the 2.4-GHz band, shorter range but compatible with the 802.11b
    - 802.11e - adding QoS features and multimedia support, critical to wireless home networks for video on demand, audio on demand, voice over IP and high-speed Internet access
    - 802.11i - adding Advanced Encryption Standard (AES) security protocol to 802.11, stronger level of security than the current Wi-Fi Protected Access security standard
    - And many other extension …

see: www.ieee802.org/11/

IEEE 802.15 Standard

- IEEE 802.15 - The wireless personal area networks
  - 802.15.1: was adapted from the Bluetooth specification and is fully compatible with the Bluetooth 1.1
  - TG4 (low rate): provides data speeds of 20 Kbps or 250 Kbps
  - TG3 (high rate): supports data speeds of 11 Mbps to 55 Mbps
  - **Features**: Use of up to 254 network devices, dynamic device addressing, support for devices in which latency is critical, full handshaking, security provisions, and power management
  - There will be 16 channels in the 2.4-GHz band, 10 channels in the 915-MHz band, and one channel in the 868-MHz band.
  - Plans to refine the 802.15 specification to work with the Specification and Description Language (SDL), particularly SDL-88, SDL-92, and SDL-2000 updates of the International Telecommunication Union (ITU) recommendation Z.100

see: www.ieee802.org/15/
IEEE 802.16 Standard

- IEEE 802.16 - The wireless metropolitan area networks
  - Originally published in December 2001, specified fixed point-to-multipoint broadband wireless systems operating in the 10-66 GHz licensed spectrum
  - An amendment, 802.16a, approved in Jan. 2003, specified non-line-of-sight extensions in the 2-11 GHz spectrum, delivering up to 70 Mbps at distances up to 31 miles
  - Further amendment, 802.16e, enables connections for mobile devices
  - Commercialization and vendor interoperability through WiMax Forum

see: www.ieee802.org/16/

IEEE 802.20 and .21 Standards

- IEEE 802.20 - Mobile Broadband Wireless Access
  - Developing a packet based air interface standard that is optimized for the transport of IP based services for mobile BWA systems operating in licensed bands below 3.5 GHz
  - Targeting peak data rates of over 1 Mbps per user at vehicular speeds to 250 km/hour

see: www.ieee802.org/20/

- IEEE 802.21 - Handover and interoperability issues
  - Developing standards to enable handover and interoperability between heterogeneous network types including both 802 and non-802 networks

see: www.ieee802.org/21/
The Last Mile Communications

- A chain is only as strong as its weakest link
  - Data slowdown in the last mile of networking can impact the entire web browsing experience and limit the performance of promising services such as video on demand and multimedia-filled web connections.

- Purpose: Bridging the critical connection linking homes and businesses with their Internet service providers.

- Mission: To blanket sections of cities and rural areas that are not wired for broadband, or to provide an alternative to wired connections in places that are connected.
WiMax – The IEEE 802.16 Standard

- WiMax: Worldwide Interoperability for Microwave Access
  - The latest, and most-hyped, generation of fixed wireless technology
- Differentiates from earlier broadband wireless access (BWA) iterations by standardization. Currently BWA chipsets are custom-built for each BWA vendor
- Similar to Wi-Fi Alliance, WiMax Forum would bring interoperability and thus plug-and-play products
- WiMax would succeed in every geographic market, but for different reasons, in either way, it will become an inexpensive means of delivering high-speed data
  - In emerging markets for low cost voice communications
  - In developed markets for broadband Internet access

IEEE 802.16 – Original Concepts

A service provider sets an 802.16a – WiMax – transceiver atop an antenna tower. Height gives the line-of-sight service better range and coverage. The signals reach the client’s transceiver either directly or, in some cases, by bouncing off smooth surfaces. However, bounced signals are more error prone, and thereby have a much-reduced effective throughput.

The received WiMax signal is decoded and unencrypted, and the payload extracted. Ethernet traffic is bridged to a standard local area network, such as a wired Ethernet router for an enterprise network, or to a Wi-Fi access point to support nearby mobile users.
WiMax – The IEEE 802.16 Standard

- IEEE 802.16 wireless MAN is expected to provide broadband wireless Internet access for neighbors, villages, and cities similar to what was done by IEEE 802.11 wireless LAN standard for homes, coffee shops, airports and offices
- The first IEEE 802.16 standard published in April 2002. To define the wireless MAN air interface as an alternative to traditional wired connections for homes, small business and commercial buildings
- A consortium of companies known as WiMax Forum, San Jose, CA, was created to coordinate the commercial development of 802.16 products by ensuring their interoperability

WiMax Forum

- A non-profit organization comprised of broadband wireless access system manufacturers, component (silicon, RF, antenna) suppliers, software developers and carriers
- Promote WiMax brand identity and WiMax-Certified equipment to drive interoperability
  - Based on IEEE 802.16 and ETSI HiperMAN standards
  - Founded in conjunction with the original IEEE 802.16 standard for 10-66 GHz applications
  - 10-66 GHz range requires line of sight, so base stations antennas would be installed on roof of buildings
  - In Jan '03, the Forum started efforts to cover the IEEE 802.16a standard for < 11 GHz
IEEE 802.16 Developments

- To accommodate non-line-of-sight, IEEE published 802.16a in Jan 2003
  - It operates in licensed and unlicensed (either 2.4 or 5 GHz) frequencies between 2 GHz and 11 GHz using OFDM (similar to 802.11a and 802.11g)

- 802.16 MAC supports different physical layer specifications
  - Every base station dynamically distributes uplink and downlink bandwidth to subscriber stations using TDMA, completely different from 802.11 MAC which uses carrier-sensing mechanisms that don’t provide effective bandwidth control over the radio link

IEEE 802.16e: Mobile WiMax

- The most recent revision of IEEE 802.16 to support mobile user services at high data rates
- Business model: To keep service cost affordable by
  - An advanced over-the-air protocol
    - Minimizing the number of required base stations
    - Reducing deployment cost
  - Ability to add applications based on service demand
  - Option to begin with a limited network and increase capacity according to demand
  - Having low cost, advanced terminals
  - Use of low cost IP routers in an all-IP network configuration
IEEE 802.16e: Advantages

- Mobile IP at its core for seamless handover of services
- Use of all-IP networks; so that the support of E2E QoS can be easier maintained using IP QoS provisioning methods available for IP multimedia applications
- Scalable transmission coding: A device can communicate with its closest base station using one of various transmission coding schemes (depending on signal quality, interference, internal processing capability, etc.)
- Spectral efficiency: Combination of Tx coding schemes with several channel size options (up to 20 MHz); ability to group sub-carriers to use spectrum efficiently
- Advanced over-the-air QoS: Using all-IP nature and design Tx scheduler to ensure QoS for users with different traffic
- Non-line-of-sight and use of smart antennas

IEEE 802.16 Standards

<table>
<thead>
<tr>
<th></th>
<th>802.16 Line of sight</th>
<th>802.16a/REVd Non line of sight</th>
<th>802.16e Non line of sight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status of Standard</td>
<td>Dec 2001</td>
<td>802.16a: Jan 2003, 802.16REVd: Q3 ’04</td>
<td>Completed Dec ’05</td>
</tr>
<tr>
<td>Spectrum</td>
<td>10 - 66 GHz</td>
<td>&lt; 11 GHz: 2.5, 3.5 GHz licensed, 5.8 GHz license-exempt</td>
<td>&lt; 6 GHz</td>
</tr>
<tr>
<td>Aggregate Bit Rate</td>
<td>32–134 Mb/s in 28 MHz of spectrum</td>
<td>Up to 75 Mbps in 20 MHz of spectrum</td>
<td>Up to 15 Mbps in 5 MHz of spectrum</td>
</tr>
<tr>
<td>Mobility</td>
<td>Fixed</td>
<td>Fixed outdoor &amp; indoor</td>
<td>Portable/Mobile</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>20, 25 and 28 MHz</td>
<td>Flexible channel bandwidths between 1.25 and 20 MHz</td>
<td>Same as 802.16a with more “sub-channels” for low power</td>
</tr>
<tr>
<td>Typical Cell Radius</td>
<td>1-3 miles; up to 5 miles.</td>
<td>3 to 5 miles; Max range 30 miles based on tower height and topography</td>
<td>1-3 miles</td>
</tr>
</tbody>
</table>

Typical Cell Radius

2007 A. Jamalipour 81
Technology Comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Burst Speed</th>
<th>Average User Throughput</th>
<th>Capacity</th>
<th>Other Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPRS</td>
<td>53 kbps</td>
<td>30-40 kbps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EDGE</td>
<td>200 kbps</td>
<td>100-130 kbps</td>
<td>Double that of GPRS</td>
<td>Backward compatibility with GPRS</td>
</tr>
<tr>
<td>UMTS</td>
<td>384 kbps</td>
<td>220-320 kbps</td>
<td>Increased over EDGE for high BW apps.</td>
<td>Simultaneous voice/data operation, enhanced security, QoS, multimedia support, reduced latency</td>
</tr>
<tr>
<td>UMTS-HSDPA</td>
<td>2-3 Mbps</td>
<td>550-1100 kbps</td>
<td>2.5-3.5 times over WCDMA</td>
<td>Backward compatible with WCDMA</td>
</tr>
<tr>
<td>CDMA20001 XRTT</td>
<td>144 kbps</td>
<td>50-70 kbps</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDMA20001 XEV-DO</td>
<td>800 kbps</td>
<td>300-500 kbps</td>
<td></td>
<td>Optimized for data, VoIP in development</td>
</tr>
<tr>
<td>Mobile WiMax</td>
<td>8 Mbps (in 5 MHz ch)</td>
<td>1 Mbps+ (in 5 MHz ch)</td>
<td>20% higher than HSDPA or EV-DO</td>
<td></td>
</tr>
</tbody>
</table>

Wi-Fi and WiMax

- Wi-Fi is a great technology for wireless networking, but
  - Still tightly tethered to a wired infrastructure – conventional DSL, cable-modem, leased line, or dial-up links to an Internet service provider

- WiMax is coming to add the short wireless connectivity and to revolutionize the last-mile service delivery for broadband homes and businesses

- WiMax will compete against DSL, cable, and dial-up for homes and businesses

- WiMax protocols make efficient use of bandwidth and also allow it to carry many different types of traffics not just TCP/IP but also ATM and voice traffic; also allows for strong encryption for user’s data privacy
Wi-Fi – WiMax: Clear Differences

- WiMax is not an extension of Wi-Fi
  - Wi-Fi is a LAN standard under IEEE 802.11 standard for indoor use, to distribute Internet access to a bunch of home and office computers
  - WiMax is a wireless replacement for a wired broadband connection; i.e. a new way of getting Internet access into home or office, more cheaply and easily than usual wires of telephone
  - The two standards use different chip sets and different schemes for QoS and security
  - They may or may not operate in the same regions of the radio spectrum
  - They operate with different assumptions about radio environments where they work
  - WiMax is ideal for a fixed point-to-multipoint network, but inappropriate for a LAN

802.16 and 802.11 Standards

<table>
<thead>
<tr>
<th></th>
<th>802.11</th>
<th>802.16</th>
<th>Technical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range</td>
<td>Optimized for 100 meters</td>
<td>Optimized for typical cell size of 7-10 km</td>
<td>802.16 PHY tolerates the greater multi-path delay spreads caused by distance</td>
</tr>
<tr>
<td>Coverage</td>
<td>Add access points or high gain antenna for greater coverage</td>
<td>Optimized for outdoor environments (trees, buildings, users spread out over distance)</td>
<td>802.16: 256 OFDM (vs. 64 OFDM) Mesh option part of 802.16 spec</td>
</tr>
<tr>
<td>Scalability</td>
<td>Optimized for indoor environments and users within 100m of each other</td>
<td>Standard support for advanced antenna techniques &amp; mesh</td>
<td>Micro cell planning (MAN) has different requirements than micro-cell (LAN) planning</td>
</tr>
<tr>
<td>Bit rate</td>
<td>Channel bandwidth is wide (20 MHz) and fixed OK for small cell sizes</td>
<td>Channel bandwidth is flexible from 1.5 MHz to 20 MHz for Metropolitan Area cell planning</td>
<td>Slightly higher modulation scheme yields slightly higher data throughput</td>
</tr>
<tr>
<td>QoS</td>
<td>No QoS support today → 802.11e working to standardize</td>
<td>QoS designed in for voice/video, differentiated services</td>
<td>802.11: contention-based MAC (CSMA) 802.16: grant request MAC</td>
</tr>
</tbody>
</table>
Worldwide Mobile WiMax Progress

- Korea: KT and SK Telecom already deployed mobile WiMax in specific locations throughout the country
- Sprint/Nextel are deploying 802.16e compliant network with a forecast of 100m subscribers by the end of 2008
- BT bids for 2.5GHz spectrum in the Ofcom auctions for deploying efficient WiMax service toward the end of 2007
- Operators like Clearwire (in US, Denmark, Belgium, Ireland, Mexico) are expected to utilize mobile WiMax for new 3G/4G customers
- Manufacturers like Samsung, Nortel Networks, Alcatel, Nokia-Siemens Networks are all involved in 802.16e
- Companies involved in operator proprietary broadband wireless such as Alvarion and Proxim are developing 802.16e compliant platforms
- Chipset provider like Wavesat, Runcom Tech., Beceem Commun. are developing OFDMA chipsets with interoperability solutions

Mobile Broadband Wireless Access

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IEEE 802.20: The MBWA

- AKA Mobile-Fi
- March 2002: The Mobile Broadband Wireless Access was formed within the IEEE 802.16 committee
- Dec 2002: It was concluded that 802.16 and MBWA address two different markets; the IEEE 802.20 Working Group was established
- Three major projects:
  - IEEE 802.11: WLAN within around 100 meters
  - IEEE 802.16: WMAN mainly to support fixed broadband wireless systems
    - 802.16e: Giving mobility to the WMAN
  - IEEE 802.20: WWAN essentially with (vehicular) mobility and coverage of cellular networks, but with Wi-Fi speed
- All three standards define MAC and PHY layer specs.

IEEE 802.20 – Criteria

1. Broad market potential
2. Compatibility
3. Distinct identity
4. Technical feasibility
5. Economical feasibility

- Mission: IEEE 802.20 to be an efficient packet based air interface optimized for transport of IP-based data for worldwide deployment of affordable, ubiquitous, always-on, and interoperable multi-vendor MBWA networks

“http://grouper.ieee.org/groups/802/20/Documents.htm”
IEEE 802.20 – Criteria

1. Broad market potential
   - Due to narrowband feature of cellular systems and need for a technology for good service to Internet-based apps.

2. Compatibility
   - Must conform to IEEE 802.1D (MAC Bridges) and IEEE 802.1F (VLAN Bridges)

3. Distinct identity
   - To be different from any other IEEE 802 standard

4. Technical feasibility
   - Be small-scale proprietary systems using available components (modems, radios, antennas)

5. Economical feasibility
   - Cost factors of mobile services, investment return, etc.

IEEE 802.20 – Scope and Purpose

- Scope: To define physical and MAC layers for interoperable mobile broadband wireless access
  - Operation in the licensed spectrum below 3.5 GHz
  - Optimized for IP-data transport
  - Peak data rates larger than 1Mbps per user
  - Support of various vehicular mobility classes up to 250 km/h
  - Targeting spectral efficiency, larger sustained user data rates, larger number of active users

- Purpose: Fill the gap between “low BW-high mobility” and “high BW-low mobility” systems
  - Seamless integration of home/office/mobile domains
  - A worldwide network that is cost-effective, spectrum-efficient, always on, and interoperable
  - Support of RT/NRT apps., inter-technology roaming, QoS
IEEE 802.20 – Technical Specifications

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Target Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicular mobility classes</td>
<td>Up to 20 km/h</td>
</tr>
<tr>
<td>Sustained spectral efficiency</td>
<td>&gt; 1 bit/s/Hz/cell</td>
</tr>
<tr>
<td>Downlink peak user data rate</td>
<td>&gt; 1 Mbps</td>
</tr>
<tr>
<td>Uplink peak user data rate</td>
<td>&gt; 300 kbps</td>
</tr>
<tr>
<td>DL peak aggregate data rate per cell</td>
<td>&gt; 4 Mbps</td>
</tr>
<tr>
<td>UL peak aggregate data rate per cell</td>
<td>&gt; 800 kbps</td>
</tr>
<tr>
<td>Airlink MAC frame RTT</td>
<td>&lt; 10 msec</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>1.25 MHz, 5 MHz</td>
</tr>
<tr>
<td>Cell size</td>
<td>For ubiquitous MANs, reusing existing infrastructure of cellular systems</td>
</tr>
<tr>
<td>Spectrum (max operating frequency)</td>
<td>&lt; 3.5 GHz</td>
</tr>
<tr>
<td>Spectrum (frequency arrangement)</td>
<td>FDD (2x1.25 MHz paired) and TDD (one 2.5 MHz unpaired)</td>
</tr>
<tr>
<td>Spectrum allocations</td>
<td>Licensed mobile spectrum</td>
</tr>
<tr>
<td>Spectrum support</td>
<td>AES</td>
</tr>
</tbody>
</table>

Available BW at Base Station

<table>
<thead>
<tr>
<th>Data Rate</th>
<th>1.25 MHz</th>
<th>5 MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak user data rate (DL)</td>
<td>&gt; 1 Mbps</td>
<td>&gt; 4 Mbps</td>
</tr>
<tr>
<td>Peak user data rate (UL)</td>
<td>&gt; 300 kbps</td>
<td>&gt; 1.2 Mbps</td>
</tr>
<tr>
<td>Peak aggregate data rate per cell (DL)</td>
<td>&gt; 4 Mbps</td>
<td>&gt; 16 Mbps</td>
</tr>
<tr>
<td>Peak aggregate data rate per cell (UL)</td>
<td>&gt; 800 kbps</td>
<td>&gt; 3.2 Mbps</td>
</tr>
</tbody>
</table>

See also: IEEE P802.20-D1, Draft Standard for Mobile Broadband Wireless Access
IEEE 802.20 – Applications

- Essentially all possible applications!
  - Video
  - Web browsing
  - File transmissions including FTP and email
  - Streaming video and audio
  - VPN
  - Instant messaging, network game
  - Voice over IP

IEEE 802.20 – MAC and QoS

- MAC layer protocol: to support over 100 simultaneous active sessions per sector
  - Active session: The time duration from a user receives/transmits data with a delay less than 25 msec, with probability of no less than 0.9
  - Higher priority for delay sensitive apps. such as VoIP
- Significant change in throughput for mobile users
  - For FDD 1.25 MHz:
    - DL: 2.5 Mbps (3 km/h) to 1.25 Mbps (120 km/h)
    - UL: 1.25 Mbps (3 km/h) to 0.94 Mbps (120 km/h)
  - For FDD 5 MHz:
    - DL: 10 Mbps (3 km/h) to 5 Mbps (120 km/h)
    - UL: 5 Mbps (3 km/h) to 3.75 Mbps (120 km/h)
Air Interface Characteristics

- Layered architecture
  - A distinct separation of functionality among user, data and control planes
  - Support of multiple MAC protocol states and fast and dynamic transition among them
- Resource allocation
  - Support of fast resource allocation and release for both UL and DL for different apps. (e.g. burst IP)
- Handoff
  - Minimizing packet loss and delay for inter-cell and inter-sector handoff, and support of soft handoff
- Latency
  - Organizing packet types and categorizing them into certain classes for QoS
- Spectrum
  - Operation at licensed spectrum below 3.5 GHz for paired and unpaired channels with multiples bandwidths
- Spectral efficiency
  - Support of universal frequency reuse and a sustained spectral efficiency of 1 bit/s/Hz/cell
- User data rate management
  - Automatic selection of optimized data rate for user in different network loadings and for maintaining an appropriate level of frame error rate performance
- Multiplexing
  - OFDM for better system capacity and less intra-cell interference
Relation with Other Technologies

<table>
<thead>
<tr>
<th>Network</th>
<th>802.16e</th>
<th>802.20</th>
<th>3G</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>High data rate fixed wireless user with adjunct mobility service</td>
<td>Fully mobile, high throughput data user</td>
<td>Voice user requiring data services</td>
</tr>
<tr>
<td>Data pattern</td>
<td>Symmetric data services</td>
<td>Symmetric data services</td>
<td>Highly asymmetric data services</td>
</tr>
<tr>
<td>Services</td>
<td>Support of low-latency data and real time voice services</td>
<td>Support or low-latency data services</td>
<td>Lack of support for low latency services</td>
</tr>
<tr>
<td>Roaming</td>
<td>Local/Regional mobility and roaming support</td>
<td>Global mobility and roaming support</td>
<td>Global mobility and roaming support</td>
</tr>
<tr>
<td>MAC/PHY</td>
<td>Extensions to 802.16a MAC and PHY</td>
<td>New PHY and MAC optimized for packet data and Adaptive antennas</td>
<td>W-CDMA, cdma2000</td>
</tr>
<tr>
<td>Technology</td>
<td>Technology is optimized for and backwards compatible with fixed stations</td>
<td>Technology is optimized for full mobility</td>
<td>Technology is an evolution of GSM or IS-41</td>
</tr>
<tr>
<td>Bands</td>
<td>Licensed bands 2-6 GHz</td>
<td>Licensed bands below 3.5 GHz</td>
<td>Licensed bands below 2.7 GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>Typical channel BW &gt; 5 MHz</td>
<td>Typical channel BW &lt; 5 MHz</td>
<td>Typical channel BW &lt; 5 MHz</td>
</tr>
</tbody>
</table>

Mesh Networks

- Mesh networks can extend the coverage of wireless networks (e.g. WLAN) as well as creating new services.
IEEE 802.20 and Mesh Networking

- IEEE 802.20 (similar to its predecessors) can be used to create a mesh network
  - Other working groups in IEEE for mesh networks
    - IEEE 802.11s; using APs to form backbone of WMN
    - IEEE 802.15.5; support of WMN in wireless PANs
    - IEEE 802.16a; support of optional mesh networks with TDMA-based among stations

- IEEE 802.20
  - Adopting a cellular architecture with macro-cells, micro-cells, and pico-cells
  - Connection of IEEE 802.20 mesh network to other mesh networks (802.16a, 802.11s, 802.15.5, 3GPP, 3GPP2) to form a heterogeneous WMN would be possible too
Network Selection and Handoff Techniques

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Network Selection

- In a heterogeneous network (i.e. NGMN), the selection of the appropriate network becomes an important issue
  - For a better service to user’s need (e.g. cost)
  - For a better service to the application need (e.g. delay or throughput)
  - For a better resource management of the network(s)
  - For other reasons such as agreement among network providers, providing network traffic uniformity, inter-network interference management, etc
Network Selection Techniques

- Traditional
  - Signal strength and channel availability

- Cost-function based
  - Type of services requested by the user and the network cost according to specific parameters

- Cost function plus optimization
  - Inclusion of QoS factors, weighting factors and network priority factors in addition to the user cost function

Elimination Functions

- **Purpose:** Reduction in number of network alternatives to simplify the problem in a multi-network scenario

1. **Eliminating network candidates based on user’s mobility**
   - For example by dividing mobile users as $M_2M_1$
     - Stationary: 00 if velocity = 0 km/hour
     - Pedestrian: 01 if velocity < 10 km/hour
     - Vehicle: 11 if velocity ≥ 10 km/hour

2. **Eliminating network candidates based on current service**
   - Examples: $S_a$: audio; $S_d$: data; $S_m$: multimedia
     \[
     E_m = M_2M_1 + M_1\left(\overline{N_2} + M_2N_2N_1\right)
     \]
     \[
     E_s = \overline{N_2}\left(N_1 + \overline{N_1}S_aS_dS_m\right) + N_2S_a
     \]
   - $N_2N_1$ (Type of network): 00 2G, 01 3G, 11 WLAN, and 10 Ethernet
Analytic Hierarchy Process (AHP)

- A procedure to divide a complex problem into a number of deciding factors and integrate the relative dominance of the factors with the solution alternatives to find the optimum one.

**Implementation Steps**
- Step 1 - Structuring a problem as a decision hierarchy of independent decision elements
- Step 2 - Collecting the information about the decision elements
- Step 3 - Comparing the decision elements pair wisely on each level in matter of their importance to the elements in the level above
- Step 4 - Calculating the relative priorities of decision elements in each level
- Step 5 - Synthesizing the above results to achieve the overall weight of each solution alternative

AHP Structure

- **Level 1**: Objective of the decision problem
- **Level 2**: Decision factor 1, Decision factor 2, Decision factor N
- **Level 3**: Decision sub-factors, Decision sub-factors, Decision sub-factors
- **Level N**: Solution 1, Solution 2, Solution N
AHP Scales

<table>
<thead>
<tr>
<th>Importance</th>
<th>characterization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equally important</td>
</tr>
<tr>
<td>2</td>
<td>Weakly moderately important</td>
</tr>
<tr>
<td>3</td>
<td>Moderately important</td>
</tr>
<tr>
<td>4</td>
<td>Moderately plus important</td>
</tr>
<tr>
<td>5</td>
<td>Strongly important</td>
</tr>
<tr>
<td>6</td>
<td>Strongly plus important</td>
</tr>
<tr>
<td>7</td>
<td>Very strongly important</td>
</tr>
<tr>
<td>8</td>
<td>Very very important</td>
</tr>
<tr>
<td>9</td>
<td>Extremely important</td>
</tr>
</tbody>
</table>

Grey Relational Analysis (GRA)

- A method of selecting the best series among comparative series through building grey relationship with an ideal series

**Implementation Steps**

- Step 1 – Classifying the elements of series by three situations, larger-the-better, smaller-the-better, and nominal-the-best
- Step 2 – Defining the lower, moderate or upper bounds of series elements
- Step 3 – Normalizing individual series entities
- Step 4 – Defining the ideal series
- Step 5 – Calculating the Grey Relational Coefficients (GRCs)
- Step 6 – Selecting the alternative with the largest GRC
Bound Definition

**Comparative series:**
\[ S_i = (s_i(1), s_i(2), \ldots s_i(k)) \quad i = 1, 2, \ldots n \]

**Upper bound:**
\[ U_j = \max\{s_1(j), s_2(j), \ldots s_n(j)\} \quad j = 1, 2, \ldots k \]

**Lower bound:**
\[ L_j = \min\{s_1(j), s_2(j), \ldots s_n(j)\} \]

**Moderate bound:**
\[ (M_j = \text{the objective value of entity } j) \& (L_j < M_j < U_j) \]

Data Normalization

Assume the \( j \) th entity of series \( S_i \) is \( s_i(j) \). The normalization of \( s_i(j) \) is presented by \( s_i^*(j) \), then for larger-the-better, smaller-the-better and nominal-the-best, the normalizations are respectively:

\[ s_i^*(j) = \frac{s_i(j) - L_j}{U_j - L_j} \]
\[ s_i^*(j) = \frac{U_j - s_i(j)}{U_j - L_j} \]
\[ s_i^*(j) = 1 - \frac{|s_i(j) - M_j|}{\max\{U_j - M_j, M_j - L_j\}} \]
Grey Relational Coefficient

\[
\text{GRC} = \frac{1}{k} \sum_{j=1}^{k} \frac{\Delta_{\min} + \Delta_{\max}}{\Delta_{i} + \Delta_{\max}}
\]

where

\[
\Delta_{i} = \left| s_{0}^{*}(j) - s_{i}^{*}(j) \right|
\]

\[
\Delta_{\min} = \min_{(i, j)} \left( \left| s_{0}^{*}(j) - s_{i}^{*}(j) \right| \right)
\]

\[
\Delta_{\max} = \max_{(i, j)} \left( \left| s_{0}^{*}(j) - s_{i}^{*}(j) \right| \right)
\]

\(s_{0}^{*}(j)\) is the normalized reference series element

\(s_{i}^{*}(j)\) is the normalized comparative series element

AHP Decision Hierarchy

```
QoS
  /\     \
Availability Throughput Timeliness Reliability Security Cost
  \     /\      \      \      \      \      \      \      \\
    RSS Coverage Area Delay Response time Jitter
      \     /\      \      \      \      \      \      \      \\
        BER Burst Error Ave. no. of Retransmission/Packet
```
Network Selection Algorithm

\[
GRC_i = \frac{1}{k} \sum_{j=1}^{k} \frac{\Delta_{\min} + \Delta_{\max}}{|s_0^*(j) - s_i^*(j)| + \Delta_{\max}}
\]

\[
GRC_{N_2N_1} = E_s E_m \frac{\Delta_{\min} + \Delta_{\max}}{\sum_{j=1}^{k} w_j |s_0^*(j) - s_{N_2N_1}^*(j)| + \Delta_{\max}} = E_s E_m \frac{1}{\sum_{j=1}^{k} w_j \Delta_{j, N_2N_1} + 1}
\]

Simulation

<table>
<thead>
<tr>
<th>QoS Parameters</th>
<th>UMTS</th>
<th>WLAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput (Mb/s)</td>
<td>2</td>
<td>25</td>
</tr>
<tr>
<td>Delay (ms)</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>BER (dB)</td>
<td>(10^{-3})</td>
<td>(10^{-3})</td>
</tr>
<tr>
<td>Security (level)</td>
<td>9</td>
<td>7.5</td>
</tr>
<tr>
<td>Cost (per kbyte)</td>
<td>1</td>
<td>0.1</td>
</tr>
</tbody>
</table>
Types of Handoff

- Horizontal handoff
  - Between similar (homogeneous) networks

- Vertical handoff
  - Between dissimilar (heterogeneous) networks

- Two types of vertical handoff
  - Handoff to enhance service quality
  - Handoff to sustain an ongoing call (forced handoff)

Enhancing Service Quality

- To enhance service quality
  - Overlapped cell environment
  - Multiple network coverage
  - Candidate network capable of supporting the terminal application

Initiate handoff if a better network becomes available (compared to current network)
Sustaining Ongoing Call

- To sustain an ongoing connection
  - Signal strength drops near cell boundary
  - Initiation must begin in a timely manner
  - Target network should have time to reserve resources for admitting the handoff call

Trigger handoff initiation as soon as the terminal senses an imminent handoff

Vertical Handoff Implementation

To keep handoff blocking probability acceptably low
- Reserve resources in advance at target network
- Have an accurate handoff prediction

However exact prediction is difficult due to
- Random mobility of terminal
- Varying cell sizes

- Proposal of a vertical handoff algorithm employing the network selection technique
Vertical Handoff Algorithm

- Step I: Location Management
- Step II: Access Network Selection (to enhance service quality)
- Step III: Forced Handoff Prediction (to sustain ongoing connection)

Repeats at a pre-defined time interval $\Delta T$ and offers a unified approach.

---

Step I: Location Management

- Precisely calculating the user terminal coordinates
- Utilizing available radio access network information from the control/signaling broadcast
- Using trilateration to calculate terminal coordinates

- Similar in principle to geo-location of GPS system
- Time of arrival (TOA) based positioning used instead of received signal strength (RSS) and angle of arrival (AoA) based methods
  - Implementation relatively easy and inexpensive
  - Used in GSM and UMTS networks
- Suffers from multipath propagation and non-line of sight (NLOS) error
Step I: Location Management

- Reflection
- Scattering
- Diffraction

Step II: Access Network Selection

- Customizations of user profile and application
  - User customizes profile
  - For different applications e.g. voice, data, multimedia etc., Analytic Hierarchy Process (AHP) matrices are generated
  - AHP considers QoS parameters: throughput, timeliness, reliability, security, cost and battery power

- Eliminate candidate networks unable to support terminal application
- Eliminate candidate networks unable to support terminal mobility
- From the remaining candidate networks select the optimal network using Grey Relational Analysis (GRA)
Step II: Access Network Selection

- Rank networks based on Grey Relational Coefficient (GRC)

\[ GRC_i = \frac{\Delta_{\text{min}} + \zeta \Delta_{\text{max}}}{W \Delta_i + \zeta \Delta_{\text{max}}} \]

where:
- \( \Delta_i \) is the absolute difference between \( E_0 \) and candidates
- \( W \) is the AHP weight vector
- \( \zeta \) is a value between 0~1

- Maximum of all \( \Delta_i \)
- Minimum of all \( \Delta_i \)

\[ E_0 = [\text{max}(\text{throughput}), \text{min}(\text{timeliness}), \text{min}(\text{reliability}), \text{max}(\text{security}), \text{min}(\text{cost}), \text{min}(\text{power})] \]

The Selection Process

- If the remaining networks have a higher GRC value than the current serving network:
  - Initiate handoff to the highest ranked network

- Otherwise:
  - Proceed to Step-III i.e. forced handoff prediction
Step II: Access Network Selection

IPv6 packet network
Wired
Mobility Anchor Point (MAP)
Gateway (GW)
To other MAPs
To other GWs
PSTN
Other data network
Wired links
Access Router (AR)

Common control/signaling mechanism

Step III: Forced Handoff Prediction

- Calculate the current cell sector
  - Uses location coordinates from Step I
  - Uses cell geometry collected from broadcast
- Determine decision axis: range of sectors over which handoff is likely
- Predict if a forced handoff is imminent
**Step III: Forced Handoff Prediction**

- **Handoff Prediction**
  - Given: hysteresis value (for triggering)
  - Given: handoff threshold (crossover point beyond which handoff must be initiated)
  - Initiate handoff using following argument

\[
| (\text{Cell range-handoff threshold}) - \text{MT distance estimate} | \leq \text{hysteresis}
\]

**Diagram:**
- BS (Base Station)
- MT (Mobile Terminal)
- Cell range
- Threshold
- Hysteresis
- Decision axis

**Equation:**
\[
|hysteresis| \leq (\text{Cell range-handoff threshold} - \text{MT distance estimate})
\]

**Lower Threshold:** initiate handoff if,
\[
| (OH - d^*) - r(t_1) | \leq \text{hysteresis}
\]
Some Simulation Results

- For a MT with $v = 9$ km/h, at $\Delta T = 1.5$ min, the algorithm can achieve accuracy to within 94 m of the handoff threshold with conventional antennas.
- Adaptive antennas exhibit better performance.
- Intuitively, this can be attributed to improved precision of terminal tracking by the antenna’s main lobe.
- For the WLAN clusters, such accuracy will be enough to ensure time for resource reservation before actual crossing of boundaries.

For microcells (1 km radius)

For macrocells (3 km radius)

- For a MT with a velocity between 10 and 100 km/h, the proposed prediction algorithm can achieve accuracy to within hundreds of meters of the handoff threshold.
- The hysteresis margin would increase as $\Delta T$ increases.
- This is because with larger $\Delta T$ the MT will travel longer thereby requiring larger hysteresis margin to maintain the prediction accuracy.
Closing Remarks

- Development trend of NGMN and Wireless IP has been separated into two distinct ways:
  - Cellular based – moving from CS to PS and all IP-based
  - IP-oriented standards oriented around IEEE 802.1x and 802.2x
- No matter how these rather exclusive directions develop, the future of mobile data will hang around a heterogeneous solution that will include both approaches
- Providing QoS and security in NGMN and Wireless IP will be the task of all layers of the network protocol stack, with particular attention at the higher layers in order to be aligned with the heterogeneous nature of the future networks
- Bandwidth and resource management of large number of network users will eventually push W-LAN and W-MAN standards into licensed spectrum

Future of BcN

- Broadband convergence Network will be the key challenge for telecom engineers
- NGMN development will be an important part of BcN in order to interconnect technology advancement in mobile and fixed domains
- BcN will be the main umbrella that covers all engineering activities toward the ubiquitous communications for real-time and non-real-time applications and in particular for broadband mobile Internet applications
- Eventually, BcN will not only converge the networks, but also converge the currently split developments in cellular and non-cellular networks
Other Key Elements of NGMN

- Improved radio and antenna technology
  - Smart antennas, beam forming, MIMO, OFDM
    - Space division multiplex to increase capacity, benefit from multipath
  - Software defined radios (SDR)
    - Use of different air interfaces, download new modulation/coding/...
    - Requires a lot of processing power (UMTS RF 10000 GIPS)
  - Dynamic spectrum allocation and cognitive radio
    - Spectrum on demand results in higher overall capacity

- Core network convergence
  - IP-based, quality of service, mobile IP

- Ad-hoc technologies
  - Spontaneous communication, power saving, redundancy

- Simple and open service platform
  - Intelligence at the edge, not in the network
  - More service providers, not network operators only

Speaker’s Biography

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IEEE Distinguished Lecturer

Abbas Jamalipour holds a PhD from Nagoya University, Japan. He is the author of the first book on wireless IP and two other books, and has co-authored five books and over 180 technical papers, all in the field of wireless communications. Dr. Jamalipour has been very active within IEEE Communications Society, serving as the Chair of Satellite and Space Communications TC (2004-06); current Vice Chair of Communications Switching and Routing TC; and Chair of Chapters Coordinating Committee, Asia-Pacific Board. He is a Technical Editor of the IEEE Communications, the Wiley Int. J. of Communication Systems, and several other scholarly journals. He is a voting member of GITC and IEEE WCNC Steering Committee. He has been a Vice Chair of WCNC2003-06, Chair of Wireless Symposium at GLOBECOM2005-07, and a symposium Co-Chair of ICC2005-08, and many other conferences. He is the recipient of several prestigious awards; most recently the “Best Tutorial Paper Award” and “Distinguished Contribution to the Satellite Communications Award” both from the IEEE Communications Society in 2006, and the 2005 Telstra Award for Excellence in Teaching.