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The Wireless Utopia of The Future: An Exploration of Opportunities to Network Operators

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Abstract- The present wireless networks demonstrate tendency of convergence. Networks designed for fixed applications are embracing mobility, mobile networks are overlapping fixed, and those optimized for either voice or data are turning multimedia. Convergence may follow a number of options ranging from heterogeneous to homogeneous. The paper outlines our views of the trends of wireless network development toward convergence. It presents options and challenges, and highlights technologies and concepts that may have strong bearing on convergence. We see that variety of homogenous and heterogeneous network will coexist for sometime to come. But there will be a limited set of dominant options that would eventually lead to convergence.

I Introduction

The book of visions (WWRF Dec.2001) stipulates visionary views of the future wireless network [1]. It outlines main issues that should govern the direction of future networks. The multiplicity of the present distinct wireless networks (Blue tooth, WLAN, LMDS, MMDS, and UMTS…) demonstrate tendency of convergence along their independent individual evolution paths. Networks designed for fixed applications are embracing mobility, mobile networks are overlapping fixed, and those optimized for either voice or data are turning multimedia. While such technology advancements make up the platform of evolution of all networks, we see network developments subject to compelling forces (e.g., technology, innovation, applications, standardizations, regulation, market, and network design trends) that introduce converging and diverging effects. To varying extents, each force can be a source of convergence, divergence or both. Rules embedded in nature, however, tend to balance those forces. Perfect equilibrium leads to optimum convergence within a complex frame of challenging opportunities. Convergence may follow a number of scenarios of which we identify two:

1. Convergence on the level of interworking such that the network will seamlessly accommodate variety of heterogeneous wireless networks; and
2. Convergence on the level of technology infrastructure that render interworking a native feature of all. Such a network we termed *collaboratively transparent wireless network*, or equivalently *homogeneous network*.

The above scenarios represent the two extremes that encompass a number of shades. The present distinct wireless networks should ideally evolve into a global wireless network that possesses a number of attributes that include:

- Optimal protocol transparency.
- Versatility of Application
- True scalability.

Such a network would realize a number of advantages such as:

- Optimum utilization and adaptivity of frequency bands
- Full network robustness and carrier grade (99.999%) service availability.
- Cost reduction of network component and peripherals.

Accomplishment of such a network would require exploration and development into new areas. It may require stretching out known concepts (e.g., adaptivity, mobility, scalability and integrity) beyond their normally defined limits to purposely overlap other realms. It will require innovative breakthroughs to take place.

Within the scope of two extreme scenarios of wireless networks conversion mentioned above, this paper examines evolutionary paths of the different present wireless networks. It identifies the areas of commonalities and misalignments as potential candidates for development work considered beneficial to network operators. This leads to the development of model of future wireless network that should comprise a suitable framework of standardization activities into the future.

II Present Wireless Networks

In this section we briefly outline salient attributes of wireless networks to emphasize commonalities and differences of issues that have undergone major development.

A. Fixed Wireless Networks

They include narrowband, wideband and broadband systems that are described below.

WLL (Wireless Local Loop) is: a TDMA (Time Division Multiplexing Access) communication system used in the carrier serving areas using 3 GHz frequency band, line of sight (LOS) communication, mainly offering telephony services at 64Kbps per channel. Later developments introduce dedicated data channel and ISDN.

SRS (Subscriber Radio System) is a communication system based on TDMA technology offering 30 or 60-shared channels of 64kbps each. SRS utilizes QPSK modulation technique at 1.5-3 GHz (LOS-transmit power around 35dBm). Repeaters assure coverage in difficult-to-reach areas and extend services as far away as 720 km from the telephone exchange. Copper wires and wireless in the frequency band 450MHz extend the services from the outstation to the customer premises.

DECT (Digital Enhanced Cordless telecommunications) a cordless communication system (for voice and data) operating at 1880-1900MHz (GMSK modulation technique at 10 mw) using either TDMA or FDMA (Frequency Division Multiplexing Access) technology, permitting mobility at 20-50km/h in limited area (around 500m).
LMDS (Local Multipoint Distribution Service) is a fixed cellular broadband technology operating above 20GHz frequency band LOS communications over cell sizes of 2-6km diameters with a transmit power around 20dBm. It provides 2GHz of band.
MMDS (Multichannel Multipoint Distribution Services) is also fixed broadband cellular wireless system operating at 2.5-10GHz used to providing voice, data, Internet, and video services to rural residential. Its coverage is around 55Km using QAM (Quadrature Amplitude Modulation) or VOFDM (Vector Orthogonal Frequency Division Multiplexing) modulation scheme.
Bluetooth: wireless bluetooth technology [3] is designed as a short-range connectivity solution operating in the unlicensed 2.4GHz serving as a low cost replacement of cables between a variety of personal devices (laptop, digital camera, cellular phones). It enables a uniform interface for accessing LAN and WAN Networks through cellular phone that gives rise to personal gateway concept. Another focus of the technology is to enable ad hoc connectivity to form collaborative groups for data exchange between terminals without infrastructure need to relay their communications.

B. Mobile Wireless Networks

They include Analog and Digital Cellular telephone System.
1G 1st Generation: Analog Cellular Telephone System is deployed in the early 80s. Advanced Mobile Phone System (AMPS-800MHz), Narrowband Advanced Mobile Phone System (N-AMPS), Nordic Mobile Telephone (NMT-450MHz upgraded to 900MHz). The basic cellular system architecture is shown in Fig. 1.
2G: Digital Cellular Telephone System was introduced in early 90's. GSM (Global System for Mobile communications) is the European standard, which operates in 900MHz band using Gaussian Minimum Shift Keying (GMSK) and TDMA technology. GSM is also operating in 1800 MHz band. The US version of GSM operates at 1900 MHz.

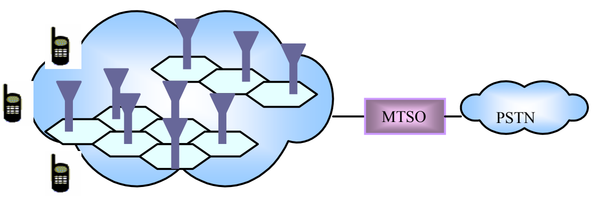

Fig.1 Cellular Communication System

3G: CDMA2000 and W-CDMA (UMTS) will offer at least 144Kbps for high-mobility and 2 Mbps for low-mobility users. They are required to support a variety of multimedia services (narrowband and broadband) ranging from telephony, fax, Internet, data transmission to video. Therefore air interfaces in these systems will need to be able to support services with more flexibility in terms of bandwidth, data rate, bit error rate, delay requirements. These features are also required in multistandard environment, so that multiband and multimode radios should be developed.
WLAN (Wireless LAN) technology standard 802.11b is mainly a standard for corporate internal wireless LAN networks operating at 2.4 GHz frequencies yielding a connection of 11 Mbps. It is currently being deployed for mobile users in "hot spots". Its successor, 802.11a, is designed to offer speed of 54Mbps and operate at 5GHz frequency band. 802.11g is adapting the modulation of 5GHz 802.11a into the 2.4 GHz band to offer comparable speed of 54 Mbps.

Table 1 summarizes attributes of different wireless networks that have received most development. It contains some that are believed to be responsible for the apparent distinct nature of each. It also includes features/capability (e.g. service, coverage, and data rate) that are specific to each network but bear minor impacts on evolution toward convergence/divergence.

III. Network Evolution Framework

A. Basis of network development

We may separate technical-related forces that impact network evolution into three sets of factors:

- Basic Technologies (e.g., modulation, coding, compression, power control).
- Distinctive features/capability (e.g., data rate, range, capacity, services, scalability).
- Network essential attributes (e.g. architecture, hierarchy, topology,).

Motivated by continual evolution of the general concepts that define of set network essential attributes, individual networks develop gradually to overcome design shortfalls. But along the way, they take advantages of advancements of basic technologies that stretch out distinctive features beyond initial boundaries to satisfy broader requirements of novel applications. Mutual interactions take place between the above sets of factors as shown in Fig. 2.

Table 1: Wireless Network features

Parameter	**WLL**	**SRS**	**WLAN**	**DECT**	**Bluetooth**	**LMDS**	**MMDS**	**GSM**	**UMTS**
Standard	Proprietary	Proprietary	IEEE802.11a IEEE802.11b IEEE802.11g HIPERLAN	ETSI DECT	IEEE802.15	IEEE802.16.1	IEEE802.16.3	ETSI GSM	3GPP
Freq. Band	< 3 GHz	< 3 GHz	2.4 GHz 5 GHz	1900 MHz	2.4 GHz	> 11 GHz	<11 GHZ	900 MHz 1800 MHz 1900 MHz	2 GHz
Multiple Access Scheme	TDMA CDMA	TDMA	DMA	TDMA FDMA	TDMA	TDMA	TDMA	TDMA	CDMA
Modulation Type	PSK	QPSK	QAM, BPSK DQPSK	GMSK	FHSS	QAM PSK	OFDM QAM	GMSK	QPSK
Services	Voice	Voice	Data	Voice & Data	Voice & Data	Multimedia	Multimedia	Voice	Multimedia
Coverage	5 km	720 km	300 m	300 m	150 ft.	5 km	> 20 km	10 km	10 km
Data Rate	64 kbps	64 kbps	54 Mbps	1.5 Mbps	10 Mbps	155 Mbps	155 Mbps	9.6 kbps	2 Mbps
Uses	Rural	Rural	Hot Spot	Residential	Residential	Operator	Operator	Operator	Operator
Data link	Circuit Switching	Circuit Switching	Packet Switching	Circuit Switching	Packet Switching	Packet Switching	Packet Switching	Circuit Switching	Packet Switching

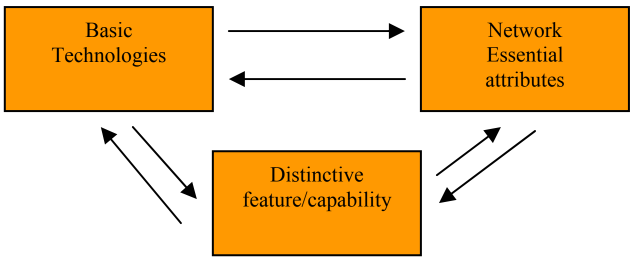

Fig. 2: Interrelation of factors responsible for network Evolution

Wireless network experienced big steps of migration on all fronts (i.e. basic technologies, features/capability, and network essential attributes). Basic technologies make up a pool of resources for other factors (i.e. features/capabilities, network essential attributes) to utilize. Basic technologies exhibit tendency to multiply into several options. Modulation, coding, power control, compression techniques, error correction, etc. spawn options that in turn spawn further options and so on. As technologies mature, individual options merge to mold a limited set of synergistic alternatives (i.e. combinations of most). It should be clear from the figure and discussion above that network features/capability hold no significance to convergence/divergence. However a strong relation remains valid between basic technologies and network essential attributes. Advancement of basic technologies strongly contributes to evolution of network essential attributes. Network essential attributes pursue same general concepts regardless of network types.

B. Development Roadmap

It should be noticed that network essential attributes follow a cyclic evolution pattern fluctuating among two or more states/concepts with sophistication added. For instance, technology moved from analog to digital, and is approaching what we term a pseudo analog (or equivalently continuous digital concept) that results from accommodating more signals levels (e.g. 1024 QAM) in a single pulse. Table 2 cites further examples. In the table, past, present, and future do not necessarily denote known generations of wireless system (i.e. 1st, 2nd, and 3rd generations).

Table 2: cyclic evolution nature of network essential attributes

Network essential attributes	**Past**	**Present**	**Future**
Architecture	Little or no functional separation	Separate functional planes (e.g. NGN)	Sophisticated network with no functional separation
Hierarchy	Hierarchical	Flat	Hierarchical
Topology	P-P	P-MP	MP-MP
Signal Representation	Analog	Digital	Pseudo Analog/continuous digital
Compliance	Proprietary	Standards	De facto
Switching Mode	Circuit Switching of Fixed size time slots	Packet Switching	Hybrid of Circuit Switching of variable size time slots that are always on, and packet switching

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C. Services vs. Applications

In this paper we draw a distinction between services and applications. Services are defined in terms of:

- Type of service (e.g. voice, data, video).
- Speed of transmission/data rate (e.g. narrowband, wideband, broadband).
- Quality/performance (e.g. reliability, BER, packet loss, delay, jitter).

Services target specific applications. Applications encompass services that are defined above but that are tailored to specific uses (e.g. enterprise, public, military, medical) along with:

- Capacity in terms of number of terminals.
- Range of coverage (PAN, WLAN, MAN, WAN, GAN). (See table 3).
- Mobility.
- Network portions where they are deployed (i.e. access, transport).
- Network type they belong to (i.e. fixed, mobile).

Table 3: Examples of networks types

Network Type	Examples
Personal Area Network (PAN)	Bluetooth, HomeRF
Wireless Local Area Network (WLAN)	HiperLAN, IEEE802.11b
Metropolitan Area Network (MAN)	Junction
Customer Area Network (CAN)	LMDS, MMDS, WLL
Wide Area Network (WAN)	GSM, UMTS
Global Area Network (GAN)	Satellite

D. Intrinsic drives for network convergence

Networks follow a pattern of developments where improvements of various degrees are introduced gradually. First, there were strong motives to introduce intelligence and integration into system design to improve aspects of services and mobility. Later, adaptivity gained wide interest as a means for optimal utilization of already exhausted and scarce resources. Capacity, and data rate benefited from such improvement. We see that a broader concept of scalability will dominate future network design. Such scalability will be the natural consequence of wide scale improvement of intelligence, integration, and adaptivity. Scalability and applications appear to bear the drives toward network convergence. Table 4 relates basic design issues and enhancements.

Table 4: Enhancements of Networks

Basic design issue	Degree of Enhancements		
	Integration/ intelligence	Adaptivity	Scalability
Services	X		X
Range		X	X
Capacity		X	X
Mobility	X		X
Data Rate		X	X
Application			X

One possible scenario evolution is expected to lead to is a general-purpose network that is adaptively scalable in relation to changes of basic design issues (i.e. services, range, capacity, mobility, data rate), which are tailored to specific applications (i.e. a network delivering scalable applications, or equivalently, a network that adapts to varying applications). Wireless system of the future will operate on the full range of spectrum to provide any data rate as deemed proper and support multimedia with quality and adopt flexible topologies (P-P to MP-MP).

E. Trends of Overlaps

A network designed for one application can satisfy requirements of another should certain attributes of its parameters are altered. We expect networks to overlap realms of each other and support multiple applications albeit with compromised quality initially. In fact we see evidence of WLAN evolving to CAN (fixed and mobile access) and to WAN for mobile data with voice as possible target later on. Equally we see WAN shrinking to Pico cells. IP network that was originally designed for bursty traffic is actively pursuing compressed packetized voice over IP (VoIP).

IV. Wireless Networks Models

In the midst of challenges and opportunities a hybrid model combining favorable features of the homogenous and heterogeneous models will likely emerge. We attempt to shed some thoughts on a few aspects of a proposed model.

A. Homogeneous Networks

A homogenous model shall converge on a number of fronts including topology, frequency band, protocols, media and services. The model depicted in Fig. (3-a) represents our view of homogeneous network. It is marked by scalable architecture and unintelligent terminal it uses a unified protocol (e.g., IPv6) and supports narrowband and broadband services.

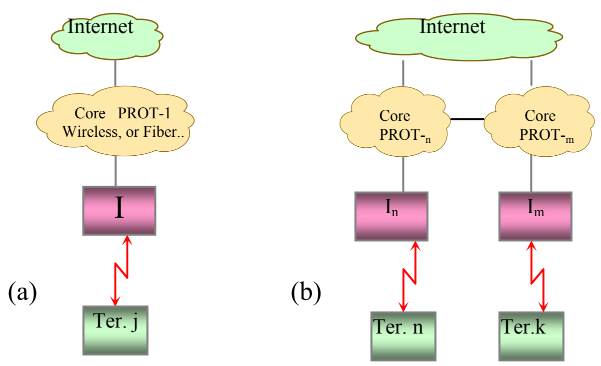

Fig.3: a) Homogeneous Model; b) Heterogeneous Model. (I: Interface, Ter: Terminal)

B. Heterogeneous Network

It comprises a number of homogeneous subnetworks, which operates on dedicated distinct set of protocols $PROT_n$. Each subnet supports certain application. A single network results from deploying gateways between subnetworks Fig. (3-b).

C. Future Wireless Network

Indications point to a number of concepts that will shape the future wireless network. They include: NGN architecture, Ad hoc network, Neural Wireless Network, software defined radio, smart antenna, UWB, and IPv6. A hybrid model as shown in Fig. 4 illustrates a possible future wireless network.

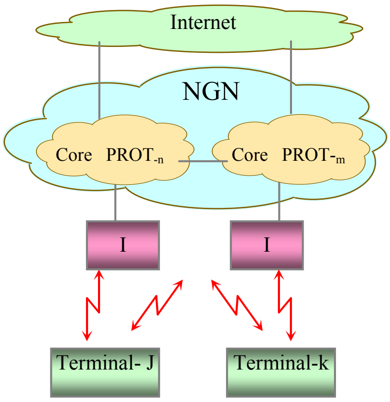

Fig. (4): Hybrid model

- Next Generation Network Architecture (NGN)

NGN is architectured around the separation of services, control and transport, Gateways adapt legacy network to the new architecture. Native NGN services extend end-to-end without gateway. The architecture simplifies network design by resorting to a limited set of protocols for terminal access and network interfaces (e.g. SIP) as shown in Fig. 5.

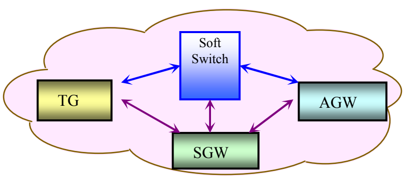

Fig. 5: NGN Architecture

- Ad-Hoc Networks

Traditional mobile wireless networks cover a geographic area divided in cells. Mobile terminals moving in a specific cell communicate directly with the base station located inside each cell. There is no peer-to-peer communications. All communications between mobiles are performed through single hop via the base station (see Fig. 1). Multi-hop routing technique is deemed more powerful [4-5]. Therefore it is applied in ad hoc networks. Mobile ad-hoc network is a self-configurable set of wireless mobile nodes interconnected to form an independent network without the aid of existing infrastructure, as shown in Fig. 6. The mobiles handle the necessary control and networking tasks using distributed control algorithms [5]. Data packets traverse multi-hop connection through mobiles nodes. The link SINR (signal-to-interference-plus-noise power ratio) [4] determines the performance of the connection in terms of routing, data rate and delay. It decreases depending on signal propagation, interferences environment and also distance between the nodes.

One approach [4] permits control of the link connectivity. As SINR degrades mobile nodes step up their transmit power to maintain connectivity. Increasing the transmit power introduces interferences. Therefore the transmit power should be managed properly. Failure of node wouldn't affect the communication. The system updates its database continuously and once a new node emerges, it is detected and identified by its neighbors.

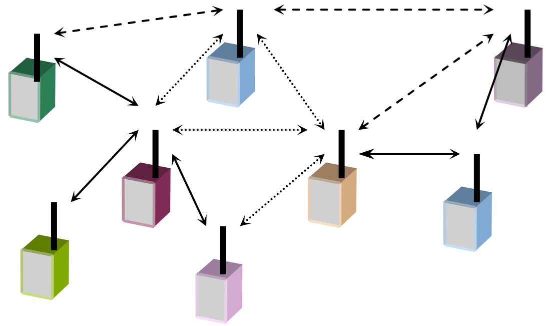

Fig. 6: Ad hoc Network structure

Another approach [5] proposes to apply IPv6 auto-configuration mechanism (such as Address configuration) to identify mobiles in a large-scale mobile ad hoc network. The purpose of address auto-configuration is to assign an address to an interface, which is unique and routable in the network. It is based on a hierarchical approach designating nodes to assume one of three different states namely *"Leader"*, "*Candidate*" (to be leader) and "host". The *Leader* is responsible for parts of the address configuration of other nodes. It is elected and should not change frequently in order to keep the network topology stable and signaling overhead small.

- Neural Wireless Networks

Wireless networks may evolve into advanced ad hoc network that may be called Neural Wireless Network (NWN), shown in Fig. 7-a. Such NWN comprises large number of terminal-nodes (host and router denoted as I/O) employing sophisticated IP protocol.

The number of I/O Fig. 7.b is a function of the traffic density and the range R that is optimized based on transmit power and minimum interference level (SINR).

The network should adapt to the number of terminals, taking in consideration their location, density, mobility and volume.

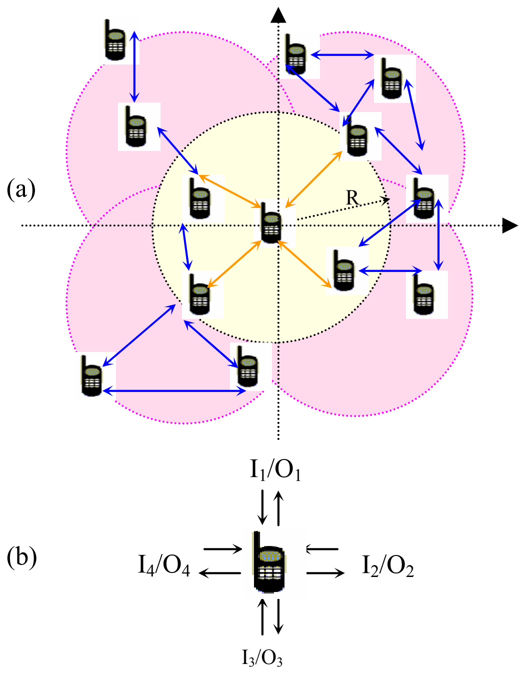

Fig. 7: a)- Neural Wireless Network Model. b)- Terminal-node- logical representation of I/O. (I/O: Input/Output)

Terminals help route packets (signaling and traffic) to adjacent nodes regardless of its actual status (idle or engaged in communication) based on flooding protocol. Then packet traffics travel from terminal-node to another in multi-hop routing, until they reach their final destination. When the terminal is off (not able to receive or initiate a call), it is considered out of service or inactive.

As terminal is moving during a call it is connected to at least one terminal neighbor. Terminal identifies in real time adjacent terminal to connect to, so as to maintain seamless communication during handover or routing process.

If there are more than n (here n= 4) terminal neighbors to a given terminal it chooses the suitable ones to connect to.

V. Research and Development Areas

Improvements are needed on all technologies. The following inventory of issues must be resolved to satisfaction to march towards a homogenous network:

- Powerful digital signal processing
- Powerful routing and signaling protocols with extremely fast neighbor discovery
- Smart antenna
- Dynamic power control (range, interference, routes)
- Reliability and Security
- **Software defined radio**
- Flexible numbering plan
- Dynamic charging capability
- Dynamic management
- ICs miniaturization
- Energy consumption
- Coding, compression algorithms
- **Ultra Wideband Modulation (UWM)**
- **IP Mobility**

Selected areas out of the above issues are elaborated below:

Software Defined Radio: The approach is to implement a software-reconfigurable radio called software defined radio (SDF), which could provide a multistandard radio supporting any transmission scheme and parameters such as modulation, spreading coding, interleaving, coding, bandwidth, frequency, slot length and burst structure.

The implementation requires powerful interference cancellation algorithms in multi-user environment and use sophisticated ADCs and DSPs, and FPGA technology as shown in Fig. 8.

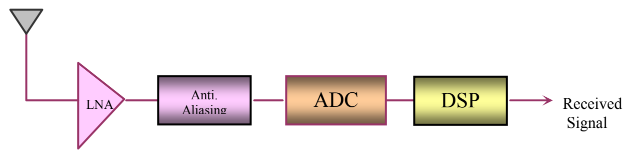

Fig. 8: Ideal software radio receiver

Ultra wide band: UWB known also as *Impulse Radio*, combined with time hopping, allows for low-cost, wideband transmitter devices and facilities scalable and flexible multiple access communications.

IP Mobility: It permits to mobile nodes to support seamless mobility. By introducing a modification on IP protocol it allows nodes to continue receiving datagrams even they moved from one place to another without need to shutdown or reinitialize the application at the new access point of the network. It involves the network protocol layer by introducing some additional control messages that allow the IP nodes to manage their IP routing tables reliably when the mobility is required. Each node is located on the network by its IP address. Mobile IP protocol requirements are:

a. Mobile node must be able to communicate with peers even after changing its link layer–point of access to the Internet.
b. Mobile must have the capability to communicate with other nodes using traditional IP protocol.
c. All signaling messages must be authenticated and preferably encrypted to ensure privacy (location information)
d. To minimize the mobile node power consumption; the number and size of messages should be minimized. The problems facing Mobile IP in the realm of secure enterprise computing are ingress filtering and firewalls.

Routing protocol: the flooding algorithm is a logical solution for neural network. But the number of packet traveling in the network increase as the number of hops increases too. One solution consist to partition the network in sub networks using an identifier (ID-Subnet) the routing mechanism is restraint to the area where the called terminal is located as shown in Fig. 9. The gateways permit the access to Internet and to other networks.

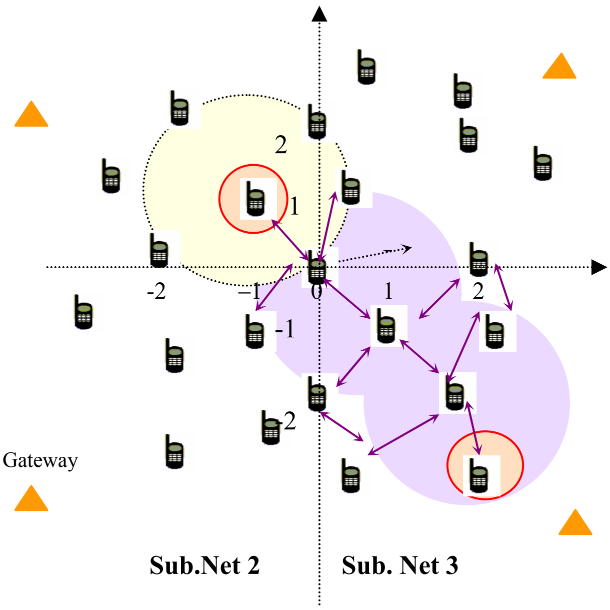

Fig. 9: Routing based on Id-Sub network

VI. Summary and Conclusion

The paper outlined our views of the trends of wireless network development toward convergence. It presented options and challenges and highlights technologies concept that may have strong influence on convergence. We see that variety of homogenous and heterogeneous network will coexist for sometime to come. But eventually, there will be limited set of dominant options that would lead to nothing but convergence.

References

[1] Wireless World Research Forum "Book of Vision" Version 1.0, Dec., 2001

[2] T. S. Rappaport and Al., " Wireless communications: Past Events and a future Perspective" IEEE Comm. Mag., pp. 148-161, May 2002

[3] C. Bisdikian " An Overview of the Bluetooth Wireless Technology" IEEE Comm, Mag. Pp 86-94, Dec. 2001

[4] A. J. Goldsmith, Stephen B. Wicker " Design challenges for energy-constrained Ad hoc wireless networks" IEEE Comm. Mag. pp 8-18, Aug. 2002.

[5] K. Weniger, M. Zitterbart "IPv6 Auto-configuration in Large scale Mobile Ad-hoc Networks" IP on Air project Institute of Telematics, University of Karlsruhe Germany 2002. weniger@tm.uka.de

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