

# Advanced Wireless Networks: 4G Technologies

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*Invited Paper*

**Abstract** –Within the wide range of issues related to 4G wireless networks, due to the scope of the ISSSTA conference, in this presentation we highlight some segments of wireless networks that will be based on spread spectrum (including UWB) physical layer and mainly discuss only network adaptability and reconfigurability issues.

## I. INTRODUCTION

The major expectation from the fourth generation (4G) of wireless communication networks is to be able to handle much higher data rates which will be in the range of 1Gbit/s in WLAN environment and 100Mbit/s in cellular networks [1]. A user, with large range of mobility, will access the network and will be able to seamlessly reconnect to different networks even within the same session. The spectra allocation is expected to be more flexible and even flexible spectra shearing among the different subnetworks is anticipated. In such, so called composite radio environment (CRE), there will be need for more adaptive and reconfigurable solutions on all layers in the network. In other words there will be need for adaptive link, MAC [8], network and TCP layer including crosslayer optimisation. This also refers to mobility management and adaptive radio resource management. The composite radio environment will include presence of WLAN, cellular mobile networks, digital audio and video broadcasting, satellite, mobile ad hoc and sensor networks.

Within the more advanced solutions focus will be on active networks [3,4] including programmable networks, [9,10] evolution to 4G wireless networks, programmable 4G mobile network architecture, cognitive packet networks, the random neural networks based algorithms, game theory models in cognitive radio networks, cognitive radio networks as a game and biologically inspired networks including bionet architectures [11].

The networks management will deal with topics such as self-organization in 4G networks, mobile agent based network management [5], mobile agent platform, mobile agents in multi-operator networks, integration of routing algorithm and mobile agents and ad hoc network management.

The network information theory [12, 13] has become an important segment of the research dealing with effective and transport capacity of advanced cellular network, capacity of ad hoc networks, information theory and network architectures, cooperative transmission in wireless multi-hop ad hoc networks, network coding, capacity of wireless networks using MIMO technology and capacity of sensor networks with many to one transmissions. In addition,

energy efficient wireless networks and QoS management will be also in the focus of research. Due to limited space, and a specific profile of ISSSTA conference, in this presentation we will comment on some of the issues listed above. For a variety of other issues the reader is referred to [2] and references therein as a starting point.

## II. 4G NETWORKS AND COMPOSITE RADIO ENVIRONMENT

In the wireless communications community we are witnessing more and more the existence of the *composite radio environment (CRE)* and as a consequence the need for *reconfigurability* concepts.

The CRE assumes that different radio networks can be cooperating components in a heterogeneous wireless access infrastructure, through which network providers can more efficiently achieve the required capacity and QoS levels. Reconfigurability enables terminals and network elements to dynamically select and adapt to the most appropriate radio access technologies for handling conditions encountered in specific service area regions and time zones of the day. Both concepts pose new requirements on the management of wireless systems.

Nowadays, a multiplicity of radio access technology (RAT) standards are used in wireless communications. As shown in Fig. 1, these technologies can be roughly categorized into four sets:

- Cellular networks that include second-generation (2G) mobile systems, such as Global System for Mobile Communications (GSM) [8], and their evolutions, often called 2.5G systems, such as enhanced digital GSM evolution (EDGE), General Packet Radio Service (GPRS) [4] and IS 136 in US. These systems are based on TDMA technology. Third-generation (3G) mobile networks, known as Universal Mobile Telecommunications Systems (UMTS) (WCDMA and cdma2000) [8] are based on CDMA technology that provides up to 2Mbit/s. In these networks 4G solutions are expected to provide up to 100 Mbit/s. The solutions will be based on combination of multicarrier (including MC CDMA) and space time signal formats. The network architectures include macro, micro and pico cellular networks and home (HAN) and personal area networks (PAN). Short range communications will be using ultra wide band (UWB) communications (spread spectrum).

- Broadband radio access networks (BRANs) or wireless local area networks (WLANs), which are expected to provide up to 1Gbit/s in 4G. These technologies are based on OFDMA and space time coding.

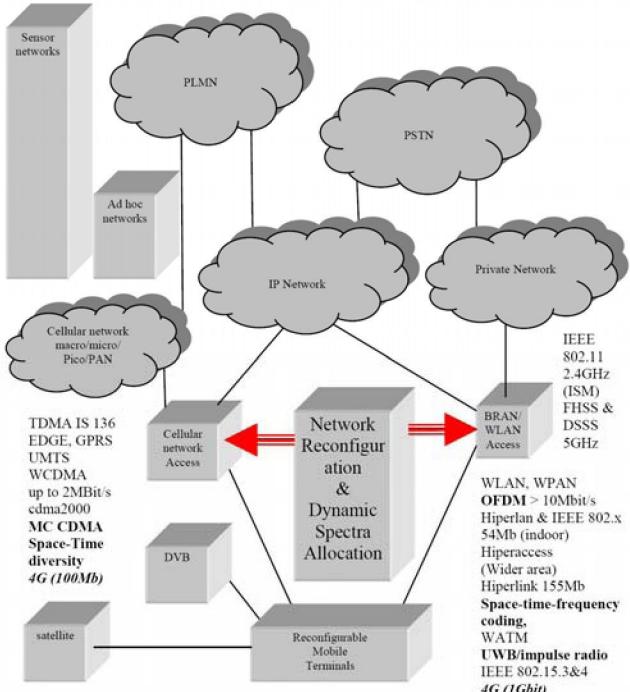


Figure 1. Composite radio environment in 4G networks

- Digital voice and video broadcasting (DVB) [6] and satellite communications will be using OFDMA signalling formats.
- Ad hoc and sensor networks with emerging applications.

Although 4G is open for new multiple access schemes, the CRE concept remains attractive for increasing the service provision efficiency and the exploitation possibilities of the available RATs. The main assumption is that the different radio networks, GPRS, UMTS, BRAN/WLAN, DVB, and so on, can be components of a heterogeneous wireless access infrastructure. A network provider (NP) can own several components of the CR infrastructure (in other words, can own licenses for deploying and operating different RATs), and can also cooperate with affiliated NPs. In any case, an NP can rely on several alternate radio networks and technologies, for achieving the required capacity and quality of service (QoS) levels, in a cost-efficient manner. Users are directed to the most appropriate radio networks and technologies, at different service area regions and time zones of the day, based on profile requirements and network performance criteria.

The management system in each network manages a specific radio technology; however, the platforms can cooperate. The fixed (core and backbone) network will consist of public and private segments based on IPv4 and IPv6-based infrastructure. Mobile IP (MIP) will enable the maintenance of IP-level connectivity regardless of the likely changes in the underlying radio technologies used that will be imposed by the CRE concept.

Fig. 2 depicts the architecture of a terminal that is capable of operating in a CRE context. The terminals include software and hardware components (layer 1 and 2 functionalities) for operating with different systems. The higher protocol layers, in accordance with their peer entities in the network, support continuous access to IP-based applications. Different protocol boosters can further enhance the efficiency of the protocol stack.

Most communications networks are subject to time and regional variations in traffic demands, which lead to variations in the degree to which the spectrum is utilized. Therefore, a service's radio spectrum can be underused at certain times or geographical areas, while another service may experience a shortage at the same time/place. Given the high economic value placed on the radio spectrum and the importance of spectrum efficiency, it is clear that wastage of radio spectrum must be avoided. These issues provide the motivation for a scheme called dynamic spectrum allocation (DSA), which aims to manage the spectrum utilized by a converged radio system and share it between participating radio networks over space and time to increase overall spectrum efficiency as shown in Fig. 3.

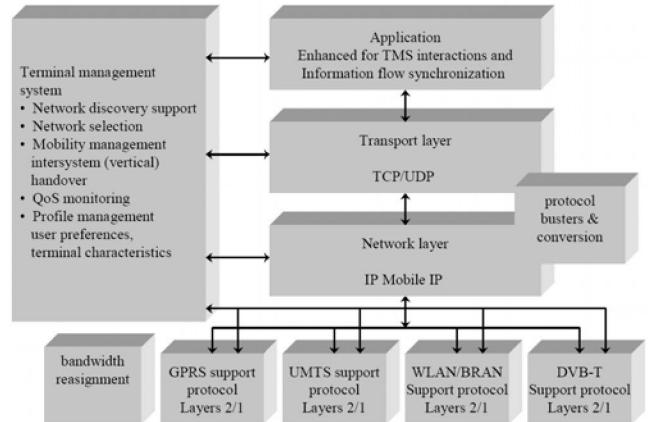


Figure 2. Architecture of a terminal that operates in a composite radio environment

Composite radio systems and reconfigurability, discussed above, are potential enablers of DSA systems. Composite radio systems allow seamless delivery of services through the most appropriate access network, and close network cooperation can facilitate the sharing not only of services, but also of spectrum.

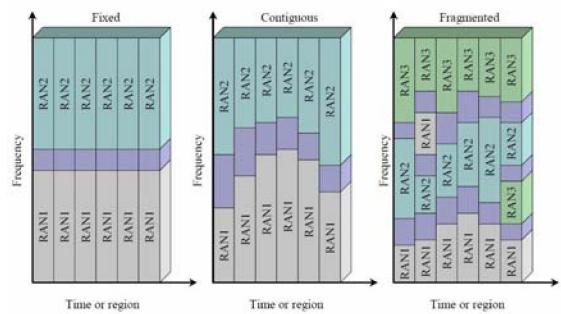


Figure 3. Fixed spectrum allocation compared to contiguous and fragmented DSA.

### III. PROTOCOL BOOSTERS

As pointed out in Fig. 2, an element of the reconfiguration in 4G networks are protocol boosters.

A protocol booster is a software or hardware module that transparently improves protocol performance. The booster can reside anywhere in the network or end systems, and may operate independently (one-element booster), or in cooperation with other protocol boosters (multi-element booster). Protocol boosters provide an architectural alternative to existing protocol adaptation techniques, such as protocol conversion.

A protocol booster is a supporting agent that by itself is not a protocol. It may add, delete, or delay protocol messages, but never originates, terminates, or converts that protocol. A multi-element protocol booster may define new protocol messages to exchange among themselves, but these protocols are originated and terminated by protocol booster elements, and are not visible or meaningful external to the booster. Fig. 4 shows the information flow in a generic two-element booster. A protocol booster is transparent to the protocol being boosted. Thus, the elimination of a protocol booster will not prevent end-to-end communication, as would, for example, the removal of one end of a conversion (e.g., TCP/IP header compression unit [7]). In what follows we will present examples of protocol boosters.

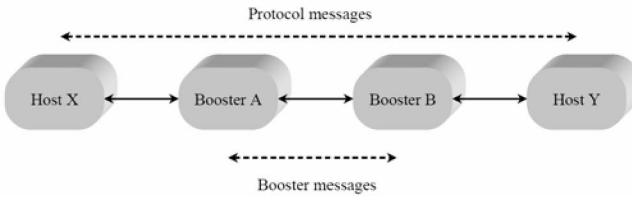


Figure 4. Two-element booster

*1) One-Element Error Detection Booster for UDP:* UDP has an optional 16-bit checksum field in the header. If it contains the value zero, it means that the checksum was not computed by the source. Computing this checksum may be wasteful on a reliable LAN. On the other hand, if errors are possible, the checksum greatly improves data integrity. A transmitter sending data does not compute a checksum for either local or remote destinations. For reliable local communication, this saves the checksum computation (at the source and destination). For wide-area communication, the single-element error detection booster computes the checksum and puts it into the UDP header. The booster could be located either in the source host (below the level of UDP) or in a gateway machine.

*2) One-Element ACK Compression Booster for TCP:* On a system with asymmetric channel speeds, such as broadcast satellite, the forward (data) channel may be considerably faster than the return (ACK) channel. On such a system, many TCP ACK's may build up in a queue, increasing round-trip time, and thus reducing the transmission rate for a given TCP window size. The nature of TCP's cumulative ACK's means that any ACK acknowledges at least as many bytes of data as any earlier ACK. Consequently, if several ACK's are in a queue, it is

necessary to keep only the ACK that has arrived most recently. A simple ACK compression booster could assure that only a single ACK exists in the queue for each TCP connection. (A more sophisticated ACK compression booster allows some duplicate ACK's to pass, allowing the TCP transmitter to get a better picture of network congestion.) The booster increases the protocol performance because it reduces the ACK latency, and allows faster transmission for a given window size.

*3) One-Element Congestion Control Booster for TCP:* Congestion control reduces buffer overflow loss by reducing the transmission rate at the source when the network is congested. A TCP transmitter deduces information about network congestion by examining acknowledgments (ACK's) sent by the TCP receiver. If the transmitter sees several ACK's with the same sequence number, then it assumes that network congestion caused a loss of data messages. If congestion is noted in a subnet, then a congestion control booster could artificially produce duplicate ACK's. The TCP receiver would think that data messages have been lost because of congestion, and would reduce its window size, thus reducing the amount of data it injects into the network.

*4) One-Element ARQ Booster for TCP:* CP uses ARQ to retransmit data unacknowledged by the receiver when a packet loss is suspected, such as after a retransmission timeout expires. If we assume the network of Fig. 4 (except that booster B does not exist), then an ARQ booster for TCP will: 1) cache packets from Host Y; 2) if it sees a duplicate acknowledgment arrive from Host X and it has the next packet in the cache, then it deletes the acknowledgment and retransmits the next packet (because a packet must have been lost between the booster and Host X); and 3) delete packets retransmitted from Host Y that have been acknowledged by Host X. The ARQ booster improves performance by shortening the retransmission path. A typical application would be if Host X were on a wireless network and the booster were on the interface between the wireless and wireline networks.

*5) A Forward Erasure Correction Booster for IP or TCP:* For many real-time and multicast applications, forward error correction coding is desirable. The two-element FZC booster uses a packet forward error correction code and erasure decoding. The FZC booster at the transmitter side of the network adds parity packets. The FZC booster at the receiver side removes the parity packets and regenerates missing data packets. The FZC booster can be applied between any two points in a network (including the end systems). If applied to IP, then a sequence number booster adds sequence number information to the data packets before the first FZC booster. If applied to TCP (or any protocol with sequence number information), then the FZC booster can be more efficient because: 1) it does not need to add sequence numbers, and 2) it could add new parity information on TCP retransmissions (rather than repeating the same parities). At the receiver side, the FZC booster could combine information from multiple TCP retransmissions for FZC decoding.

6) *Two-Element Jitter Control Booster for IP*: For realtime communication, we may be interested in bounding the amount of jitter that occurs in the network. A jitter control booster can be used to reduce jitter at the expense of increased latency. At the first booster element, timestamps are generated for each data message that passes. These timestamps are transmitted to the second booster element, which delays messages and attempts to reproduce the intermessage interval that was measured by the first booster element.

7) *Two-Element Selective ARQ Booster for IP or TCP*: For links with significant error rates using a selective ARQ protocol (with selective acknowledgment and selective retransmission) can significantly improve the efficiency compared to using TCP's ARQ (with cumulative acknowledgment and possibly go-back-N retransmission). The two-element ARQ booster uses a selective ARQ booster to supplement TCP by: 1) caching packets in the upstream booster, 2) sending negative acknowledgments when gaps are detected in the downstream booster, and 3) selectively retransmitting the packets requested in the negative acknowledgments (if they are in the cache).

#### IV. HYBRID 4G WIRELESS NETWORK PROTOCOLS

As indicated in [8], there are two basic types of structure for WLAN.

1) *Infrastructure WLAN: BS-oriented network*. Single-hop (or cellular) networks that require fixed base stations interconnected by a wired backbone.

2) *Non-infrastructure WLAN: Ad hoc WLAN*. Unlike the BS-oriented network, which has BSs providing coverage for MHs, ad hoc networks do not have any centralized administration or standard support services regularly available on the network to which the hosts may normally be connected. MHs depend on each other for communication.

The BS-oriented network is more reliable and has better performance. However, the ad hoc network topology is more desirable because of its low cost, plug-and-play property, flexibility, minimal human interaction requirements, and especially battery power efficiency. It is suitable for communication in a closed area-for example, on a campus or in a building. To combine their strength, possible 4G concepts might prefer to add BSs to an ad hoc network.

Since a mobile host may be in BS-oriented mode, one-hop direct-transmission mode, or two-hop direct-transmission mode, it is important that we understand the timing for mode transition.

Fig. 5 shows the state transition diagram. The meaning and timing of each transition are explained below.

- a) The receiver can receive the sender's signal directly.
- b) The receiver is a neighbour of a neighbour of the sender.
- c) Neither case a) nor b).

- d) The receiver can no longer hear the sender's signal. However, a neighbour of the sender can communicate with the receiver directly.
- e) The receiver discovers that it can hear the sender's signal directly.
- f) The receiver can no longer hear the sender's signal, and none of the sender's neighbours can communicate directly with the receiver.
- g) The receiver discovers that it can hear the sender's signal directly.
- h) No neighbours of the sender can communicate with the receiver directly.
- i) The sender's original relay neighbour fails. However, the sender can find another neighbour that can communicate with the receiver directly.
- j) The handoff from one BS to another.

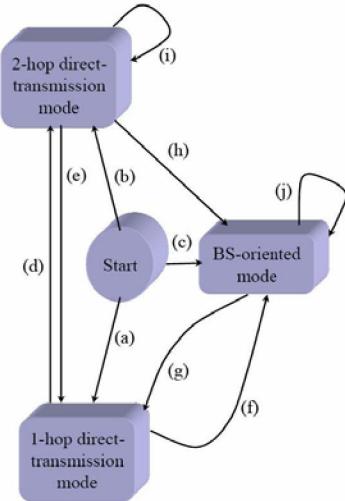


Figure 5. Transition diagram for transmission mode.

#### V. GREEN WIRELESS NETWORKS

4G wireless networks might be using a spatial notching (angle  $\alpha$ ) to completely suppress antenna radiation towards the user as illustrated in Fig. 6 and Fig. 7. These solutions will be referred to as "Green Wireless Networks" for obvious reason. This approach may be also used to reduce the interference between PAN and cellular or WLAN network and open new dimension in spectrum sharing concept. In mobile environment in the periods when the notch coincides with the direction of the base station (access point) the multi-hop protocol as discussed in the previous section can be used. In addition, to reduce the overall transmit power a cooperative transmit diversity, discussed in [2], and adaptive MAC protocol, discussed in [8], can be used.

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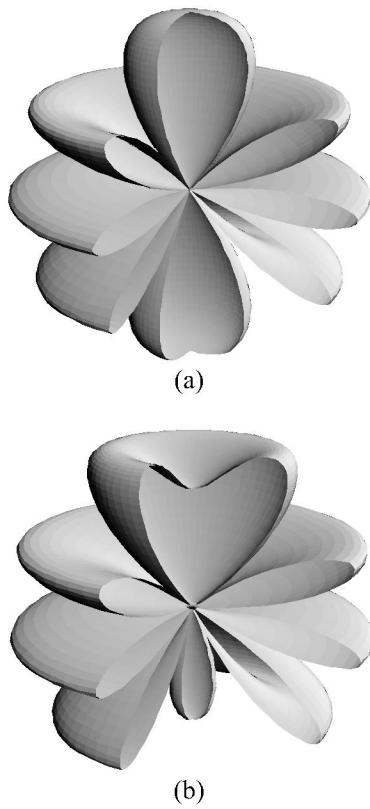


Figure 6. Three-dimensional amplitude patterns of a 2-element uniform amplitude array for  $d = 2\lambda$ , directioned towards  
a)  $\theta_0 = 0^\circ$ , b)  $\theta_0 = 60^\circ$

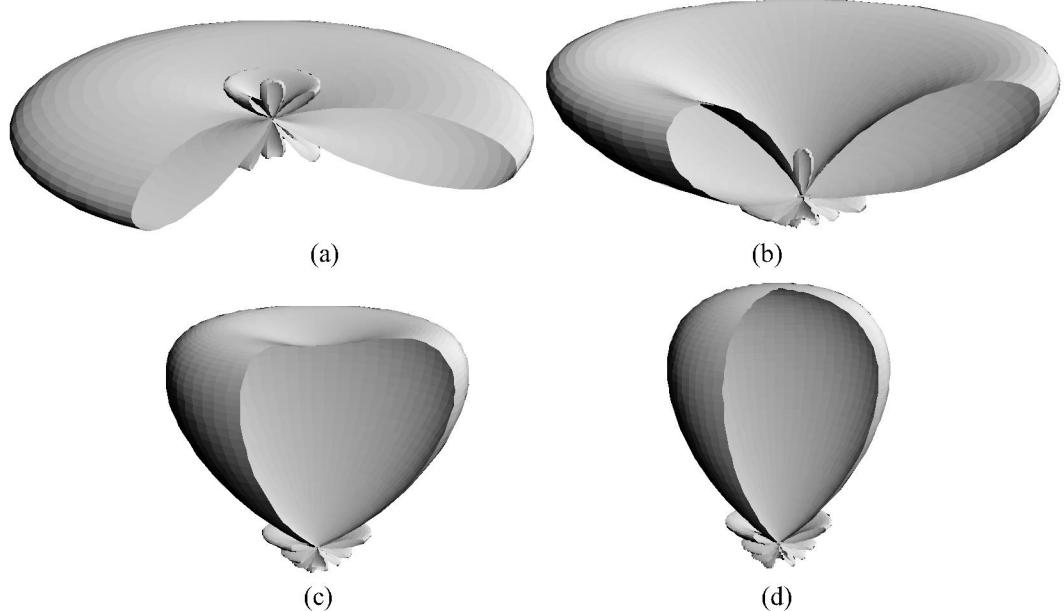


Figure 7. Three-dimensional amplitude patterns of a 10-element uniform amplitude array for  $d = \lambda / 4$ , directioned towards  
a)  $\theta_0 = 0^\circ$ , b)  $\theta_0 = 30^\circ$ , c)  $\theta_0 = 60^\circ$ , d)  $\theta_0 = 90^\circ$