



Willie W. Lu

## 4G MOBILE RESEARCH IN ASIA

**W**ireless communications is more than just a convenience. When the global perspective is considered, wireless stands to be the method most people will use to connect to the Internet. Thus, to reach their fullest potential, all the benefits we associate with the World Wide Web today — multimedia, e-commerce, unified messaging, and peer-to-peer networking — must extend to the wireless environment. Asia is and will continue to be a living laboratory for the digital opportunities presented by public wireless networks. This issue provides a strategic example of the current status of wireless communications relevant to emerging research and development of next-generation wireless communications in Asia, as well as an in-depth assessment of key prospectives of focused research subjects.

Asia is the most dynamic market of new-generation mobile communications with over \$50 billion investment in the next five years. 4G mobile technology — convergence of wireless mobile and wireless access — will definitely drive this growth.

Asia's 4G Mobile research focuses on the following open wireless platform architectures.

### ADAPTIVE MODULATION AND CODING (AMC)

The principle of AMC is to change the modulation and coding format (transport format) in accordance with instantaneous variations in channel conditions, subject to system restrictions. AMC extends the system's ability to adapt to good channel conditions. Channel conditions should be estimated based on feedback from the receiver. For a system with AMC, users close to the cell site are typically assigned higher-order modulation with higher code rates (e.g., 64-QAM with  $R = 3/4$  turbo codes). On the other hand, users close to the cell boundary are assigned lower-order modulation with lower code rates (e.g., QPSK with  $R = 1/2$  turbo codes).

AMC allows different data rates to be assigned to different users depending on their channel conditions. Since the channel conditions vary over time, the receiver collects a set of channel statistics that are used by both the transmitter and receiver to optimize system parameters such as modulation and coding, signal bandwidth, signal power, training period, channel estimation filters, and automatic gain control.

### ADAPTIVE HYBRID ARQ

A successful broadband wireless system must have an efficient co-designed medium access control (MAC) layer for reliable link performance over the lossy wireless channel. The corresponding MAC is designed so that the TCP/IP layer sees a

high-quality link it expects. This is achieved by an automatic retransmission and fragmentation mechanism (ARQ), where in the transmitter breaks up packets received from higher layers into smaller subpackets, which are transmitted sequentially. If a subpacket is received incorrectly, the transmitter is requested to retransmit it. ARQ can be seen as a mechanism for introducing time diversity into the system due to its capability to recover from noise, interference, and fades.

Adaptive hybrid ARQ shows significant gains over link adaptation alone (e.g., through Chase combining). Hybrid ARQ self-optimizes and adjusts automatically to channel conditions without requiring frequent or highly accurate C/I measurements:

- It adds redundancy only when needed.
- The receiver saves failed transmission attempts to help future decoding.
- Every transmission helps to increase the packet success probability.

### MIMO AND OFDM

Increasing demand for high-performance 4G broadband wireless mobile calls for use of multiple antennas at both the base station and subscriber ends. Multiple antenna technologies enable high capacities suited for Internet and multimedia services, and also dramatically increase range and reliability. This design is motivated by the growing demand for broadband wireless Internet access. The challenge for wireless broadband access lies in providing a comparable quality of service for similar cost as competing wireline technologies. The target frequency band for this system is 2–5 GHz due to favorable propagation characteristics and low radio frequency (RF) equipment cost. The broadband channel is typically a non-line-of-sight (LOS) channel and includes impairments such as time-selective and frequency-selective fading. Multiple antennas at the transmitter and receiver provide diversity in a fading environment. By employing multiple antennas, multiple spatial channels are created, and it is unlikely all the channels will fade simultaneously.

Orthogonal frequency-division multiplexing (OFDM) is chosen over a single carrier solution due to lower complexity of equalizers for high delay spread channels or high data rates. A broadband signal is broken down into multiple narrowband carriers (tones), where each carrier is more robust to multipath. In order to maintain orthogonality among tones, a cyclic prefix is added that has length greater than the expected delay spread. With proper coding and interleaving across

frequencies, multipath turns into an OFDM system advantage by yielding frequency diversity. OFDM can be implemented efficiently by using fast Fourier transform (FFT) at the transmitter and receiver. At the receiver, FFT reduces the channel response into a multiplicative constant on a tone-by-tone basis. With multiple input multiple output (MIMO), the channel response becomes a matrix. Since each tone can be equalized independently, the complexity of space-time equalizers is avoided. Multipath remains an advantage for a MIMO-OFDM system since frequency selectivity caused by multipath improves the rank distribution of the channel matrices across frequency tones, thereby increasing capacity

## OPEN BROADBAND WIRELESS CORE

The open wireless platform requires:

- Area and power-efficient broadband signal processing for wideband wireless applications
- Highest industry channel density (MOPS pooling) in flexible new base transceiver station (BTS) signal processing architectures
- BTS solutions scalable to higher clock rates and higher network capacity
- Waveform-specific processors providing new architecture for platform reuse in terminals for multiservice capability
- Terminal solutions achieving highest computational efficiency for application with high flexibility
- Powerful layered software architecture using the virtual machine programming concept

For example, the key features of an open BTS modem include:

### Multistandard air interfaces

- GSM, IS-95, cdma-2000, 3GPP WCDMA, HDR
- Proprietary standards

### Highest channel density

- 3GPP channels
- 128 cdma2000 channels
- Ability to support multiple sectors on one chip
- Grow from sectors-on-a-chip to BTS-on-a-chip

### Scalable data rates

- Support from 8 kb/s to 384 kb/s to 2 Mb/s to 10 Mb/s

### Configurable to mix voice and data

- Programmable allocation of channels

### IP-ready

- Interfaces directly via BTS IP backhaul

### Over-the-network programmable

- Remotely configurable from network operations center

The key features of an open wireless terminal include:

### Multistandard air interface

- GSM, IS-95, cdma2000, 3GPP WCDMA, W-LAN, Bluetooth

### Power efficiency

- 100 MOPS/mW

### Scalable architecture

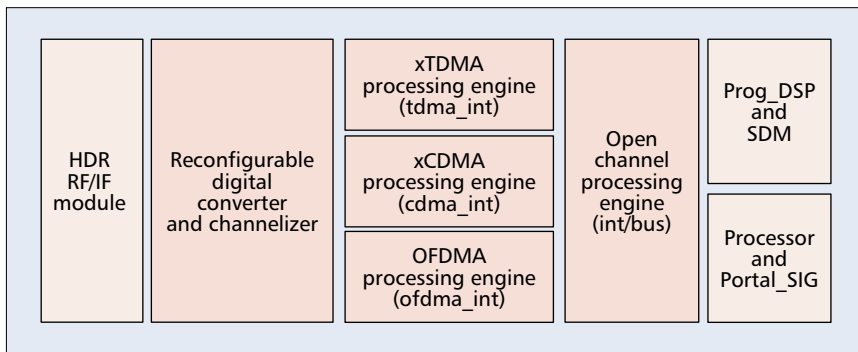
- Breaks the 384 kb/s and 2 Mb/s plateau

### High-level modem VMI

- Simplifies programming for each standard
- Enhances reuse across standards

### Integrates across many platforms

- No DSP and minimal microprocessor dependent code



■ Figure 1. The multistandard BTS engine.

### Silicon Intellectual Property (SIP) cores

- Initial engine optimized for B3G/4G applications

Figure 1 shows the multistandard BTS engine for this Open Wireless Platform; HDR means hardware-defined radio, and SDM is software-defined module.

## OPEN BACKBONE NETWORK ACCESS PLATFORM

In recent years, access aggregation technologies have been developed that allow a common access and transport network to bear the traffic of subscribers from multiple service providers. Separating access and transport from service accomplishes two points:

- It eliminates the burden of building out an access network, reducing the barrier to entry for new service providers and improving the growth potential for existing service providers.
- It promotes technical and business efficiencies for access and transport enterprises due to economies of scale and the ability to resell that access infrastructure to multiple service providers.

New systems provide end-to-end direct IP connections for users by extending access aggregation architectures to mobile broadband access. Network and service providers can leverage existing equipment, tool, and content bases to support mobile broadband end users, while the end users experience the best of the wireless and wired worlds (the broadest range of applications and end-user devices, coupled with the freedom to move and high data rates).

## SPECTRUM EFFICIENCY AND CAPACITY ENHANCEMENT

Wide-area wireless broadband systems' spectral efficiency can yield a system capacity that allows the experience to be delivered simultaneously to many users in a cell, reducing the cost of service delivery for this mass market broadband service. These systems are optimized to exploit the full potential of adaptive antenna signal processing, thereby providing robust high-speed connections for mobile users with a minimum of radio infrastructure.

The spectral efficiency of a radio system (the quantity of billable services that can be delivered in a unit of spectrum) directly impacts network economics and service quality. Spectrally efficient systems have the following characteristics:

- Reduced spectrum requirements, minimizing upfront capital expenses related to spectrum

- Reduced infrastructure requirements, minimizing capital and operating costs associated with base station sites, translating into reduced costs per subscriber and per covered population element
- High capacity, maximizing system throughput and the end-user experience even under load

The acquisition of spectrum is a key component of the cost structure of wireless systems, and two key features of spectrum have great impact on that cost: the spectral efficiency of the wireless system and the type of spectrum required to implement the system. A fully capable and commercially viable mobile broadband system can operate in as little as 5 MHz of unpaired spectrum with a total of 20 Mb/s throughput per cell in that amount of spectrum.

Spectral efficiency measures the ability of a wireless system to deliver information, “billable services,” with a given amount of radio spectrum. In cellular radio systems, spectral efficiency is measured in bits per second per Hertz per cell. Many factors contribute to the spectral efficiency of a system, including the modulation formats, air interface “overhead” (signaling information other than user data), multiple access method, and usage model, among others. The quantities just mentioned all contribute to the bits per second per Hertz dimensions of the unit. The appearance of a “per cell” dimension may seem surprising, but the throughput of a particular cell’s base station in a cellular network is almost always substantially less than that of a single cell in isolation. The reason is self-interference generated in the network, requiring the operator to allocate frequencies in blocks that are separated in space by one or more cells. This separation is represented by a reuse factor, where a lower number is representative of a more efficient system.

For example, mobile broadband systems’ spectral efficiency of 4 b/s/Hz/cell means that a mobile broadband radio network can support a given mobile customer base with far fewer sites and far less spectrum than would be required with other technologies — and hence with greatly reduced capital and operating costs. With 10 MHz of usable spectrum, for example, each mobile broadband base station would provide 40 Mb/s of access capacity. In contrast, a 2G or 3G system with a spectral efficiency of 0.1 b/s/Hz/cell would provide only 1 Mb/s of access capacity per cell in that same 10 MHz. In a capacity-limited rollout situation, a system with 2G- or 3G-like spectral efficiency would therefore require 40 times (4/0.1) the number of base stations as a wireless broadband system and have a correspondingly higher cost of service delivery.

Actually, China’s first expectation of 3G or B3G technology is to increase its service capacity and spectrum efficiency rather than demanding higher-data-rate transmission, which at this time is not the killer application.

The rollout of 3G and 4G technologies will be stunted unless wireless spectral efficiency improves. Consumer and enterprise adoption will be dependent on new wireless technologies providing significant new capabilities inexpensively and seamlessly.

## OPEN DISTRIBUTED AD HOC WIRELESS NETWORKS

Experts doubt that the current path to 3G will succeed. Current 3G migratory paths involve slowly enhancing voice-centric high-power hierarchical networks with IP overlays. Air interfaces may upgrade from GSM to WCDMA, or CDMA to 1XRTT, but such RF adaptations do not address the underlying wireless network architecture issue. Of concern is whether

or not upgrading star networks will work any better in a wireless environment than it did in wireline.

However, low-powered ad hoc mesh architected networks offer spectrally efficient high-performance solutions to this dilemma. In such peer-to-peer networks, end-user wireless handsets act as both end terminals and secure wireless routers that are part of the overall network infrastructure. Upstream and downstream transmission “hop” through subscriber handsets and fixed wireless routers to reach network access points or other end terminals. Routing infrastructure, including handsets, utilize intelligent routing capabilities to determine the best path for each transmission.

Routing for the best path must be defined for least power. That is, network nodes must be able to calculate and update routing tables to send data packets through the paths with minimal power requirements. This is different than network nodes associating with the physically closest available infrastructure. Therefore, subscriber terminals do not “shout” at a centralized base station, but rather whisper to a nearby terminal that routes the transmission to its destination. Therefore, subscriber terminals cooperate instead of competing for spectrum. Spectrum reuse increases dramatically, while overall battery consumption and RF output within a community of subscribers is reduced. Simply put, additional users enhance rather than strain network capacity.

Thus, while the cellular handset can only maintain a 144 kb/s (for example) link to the base station, the ad hoc mesh device can maintain a multimegabit link without undue interference.

To report the very active 4G R&D in this most potential region, we selected three articles for this special series. The first article from Tsinghua University introduces a new distributed wireless communications system for the 4G mobile architecture with distributed antennas, distributed processors, and distributed controlling. In the second article, some basic relations among system bandwidth, threshold SIR, maximum number of access users, as well as system spectral efficiency are studied for both traditional CDMA and LAS-CDMA, which was proposed for the 4G mobile solution in China. Lastly, Samsung reports on 4G mobile activities in Korea, which include vision, requirements, as well as enabling technologies on after-3G mobile communications.

With the strong economy growth in China and the neighboring countries, the 4G mobile system based on an open wireless platform architecture will become the next wave in wireless communications. China, Japan, Korea, Singapore, and other Asian countries are investing huge amounts of funds on this emerging 4G mobile core technology. It is predicted that Asia will be the global hub of this 4G mobile in coming years, and over 50 major wireless industries have moved their key R&D centers to East Asia, reflecting the importance of this region.

Meanwhile, 4G Mobile Forum (4GMF), WWRF, mITF, K4G, and other groups are working very hard to promote this emerging 4G mobile development on a worldwide basis. In China, 4GMF will take leadership in the next several years to make the region a worldwide base for this 4G mobile mission. Due to the current economic situation, some experts predict that 4G mobile may come much earlier than expected if 3G takes too long to take off.

The guest editor would like to thank the authors and reviewers who have given so generously of their time to make this issue a reality. The editor is also grateful to Delson Group ([www.delson.org](http://www.delson.org)) for providing the technical input of this issue and the World Wireless Congress as an international platform for R&D on emerging wireless communications.

He would like to express sincere thanks to G. S. Kuo for his initiative to prepare this topic, and his continued encouragement and support.

### BIOGRAPHY

WILLIE W. LU [SM] ([wwlu@ieee.org](mailto:wwlu@ieee.org)) is a guest visiting professor at Chinese University of Hong Kong, and senior principal wireless architect and chief China representative at Infineon Technologies. He is also an internationally recognized senior expert in emerging wireless technologies and has been a senior technical advisor for over 20 wireless communication authorities in more than 10 countries. He is an independent technical examiner for many high-tech venture capital firms in the United States, Europe, Asia, and other places, and is listed in major Who's Whos in the world. He has guest edited around 28 special issues on emerging wireless communications in IEEE, IEICE, ACM, and other major publications, and has had over 140 papers published in major professional publications. He has been chairman of numerous IEEE conferences including GLOBECOM, WCNC, VTC, and WWC, and is Wireless Feature Editor of *IEEE Communications Magazine*, *IEEE Transactions on Wireless Communications* (formerly *JSAC Wireless*), and others. He is a frequent keynote and featured speaker at lots of global technical fora, and a very well-known wireless pioneer on a worldwide basis. He is a member of ACM, IEICE, CIC, CIE, and Sigma Xi, and an adjunct professor at many world-class universities in the world.