Beyond 3G: Technologies that will shape future wireless networks

An interview with Al Javed

Articles in this issue of the Nortel Technical Journal have highlighted some of the key technologies being developed by Nortel for the next wave of wireless broadband access networks, primarily within the next two to five years. For insight into what we might expect from wireless technology beyond that timeframe, we talked with Nortel's Al Javed – a well-known and respected innovator inside and outside of the company who has been instrumental in driving Nortel's wireless technology leadership in a number of areas. Al recently announced his plans to retire later this year, after an outstanding 28-year career with the company, most recently as Leader of the Wireless Advanced Technology program. In this Q&A, he shares his perspectives on how wireless technologies in the future could change the nature of modern communications, open new paths of revenue generation for service providers, and further enhance how people and machines communicate.

Five to ten years from now, what will the "wireless world" look like? Where is technology leading us?

Over the past 20 years, our industry has focused on making true broadband mobility a reality. Soon we will reach the point where high-capacity broadband access is available anytime, anywhere, and at a very affordable cost. As well, in the core network, the 3G IP Multimedia Subsystem (IMS)/Multimedia Domain (MMD) architecture will become well established over the next three to five years. This architecture, which Nortel is implementing through its Converged Multimedia Services (CMS) thrust, will enable us to converge wireline and wireless onto a common switching core, and support the end-to-end delivery of a rich set of voice, video, data, and messaging services across both domains.

The question now is what will all that bandwidth capacity be used for, and what is in store for us beyond wide area broadband wireless systems? Some of that bandwidth will certainly be used for broadband multi-megabit services, such as mobile video and gaming, that are in increasingly high demand. I also believe that new opportunities are emerging for wireless technology, including providing the fundamental connectivity that will enable wireless networking of low-power devices (such as sensors). This connectivity will lead to new types of wireless networks, such as sensor networks, home networks, embedded networks, and automobile networks. These networks will present new technology challenges but will also enhance the way people communicate – with one another, and with their physical environments.

Al Javed, beside a prototype of Nortel's MIMO base station antenna.

How will these low-power networks enhance the way we communicate?

In the appliance and consumer electronics industries, computers – sometimes just simple 8-bit microprocessors – are embedded in nearly every device you can think of. It may surprise you that the most widely used operating system in the world is not Microsoft Windows or Unix, but an open-source system called TRON, developed by the Japanese electronics industry. TRON runs on the microcontrollers embedded in just about every device produced by companies in Japan and elsewhere – everything from household appliances and toys to car electronics and robotic systems for factories – and a staggering several billion of these TRON-embedded devices are shipped around the world each year.

While this computerization creates very useful devices, imagine how much more valuable they would be if they were net-

worked. And wireless is the only technology that makes sense for connecting everything together, because you can't run wires everywhere.

That's why I believe one of the next big waves will be to put a wireless communications link into every one of those embedded microcomputers, which will enable machines and environments to be operated remotely, and will allow machines to communicate directly with each other autonomously.

As these "smart" devices and appliances proliferate, we will move from person-to-machine communications (for example, someone using a BlackBerry handheld device to communicate with a fax machine) to machine-to-person and then to purely machine-to-machine communications.

In this way, wireless networking technology will help us extend our reach, increase the usefulness of systems, and gain greater control of our lives.

How will networked devices give us greater control?

Let's look at an example of a sensor network. Sensors are tiny, highly integrated single-chip devices containing very low-power radios and microprocessors that emit and receive signals containing data. They will be used everywhere, in the machines and appliances that are all around us every day, and will be useful in monitoring conditions in a variety of applications. For example, sensors in our home power meters could measure power consumption and then automatically send that reading to the power company. The power company could then use that information in real time to balance demand on its distribution grid and, perhaps, to institute time-of-day or demand-based billing.

There are potentially millions of different applications for sensor networks across many different industries, including healthcare, the military, and the environment, as well as in our homes. For instance, we could use wireless sensors to measure stress on a bridge, or monitor pollutants or pressure. We could even use sensors in our gardens to monitor water, sunlight, and fertilizer levels. Chemical and biological sensors for homeland security applications are another example.

Although still rudimentary, sensor networks are already here today. Low-power radio frequency (RF) identification (RFID) tags are being used to track packages, airline baggage, and library books, and are seen as a replacement for older bar-code technology. Implantable RFID chips are even used to track pets.

As sensor network technology matures over the next seven to ten years, I believe it will have as much impact on our lives as the Internet, allowing us to interact with our physical world in ways previously not possible.

You mentioned other types of networks, such as automobile networks, embedded networks, and home networks. How will those work?

These are just some examples of the many types of networks that are possible when you start to network the various machines, devices, and appliances around us.

For instance, in the future I may be able to deploy an entire sensor-based network around my home. Imagine that as I drive my car to within 100 meters of my house the network identifies my vehicle, authenticates that I am the driver, opens my garage door, and even transitions my voice communications or entertainment preferences from my car to my home. As I enter my house, security sensors use a biometric reading or retinal scan to authenticate my identity, and the network activates certain settings based on time-of-day and my own preferences, such as heat or light levels – all without any intervention from me.

With automobile networks, devices such as transponders could be deployed by the side of the road and as your vehicle passed by, its embedded computers could exchange information about the operation of the vehicle and about road, traffic, or other conditions.

With a low-power wireless home network, every device in our homes – stereos, televisions, PCs, fridges, stoves, even furniture – would have the ability to communicate with each other and with the outside world. For example, if the refrigerator could communicate with temperature sensors in the home and with an electrical power appliance that monitors the current cost of power as well as the demand from other appliances, the fridge could optimize its use of power while still maintaining appropriate temperature levels within the fridge.

Technologically, what will it take to get to this point?

It will require microminiaturized, highly integrated, low-power devices, such as active sensors, that consume very little power and are able to use energy from sources other than batteries. That's a very different challenge than what we have been focused on to date. Until now, we have focused on making broadband mobile capabilities possible, which requires a significant amount of power and processing capacity.

As we develop sensor technologies, we will need to design whole systems to ensure that the sensors can conserve power, requiring only micro-joules from such sources as light. Nortel is already pursuing this new branch of wireless technology with leading researchers, such as the Berkeley Sensors and Actuator Center at the University of California at Berkeley.

Then there is the challenge of designing and architecting the network to provide connectivity both locally, between low-power embedded devices, and regionally, between low-power networks and other networks or services. Most likely, a server approach will not be practical for configuration, security, and routing because of the expense and because each low-power environment – whether home or business or garden – will be unique. Therefore, we will need to equip each device in the network with capabilities, such as auto-discovery and auto-configuration, that will enable the devices to discover their environment,

know where they are in the network, and understand how to connect and communicate with other devices on that network.

From there, these devices would need to communicate outside their specific network – a home network, for instance – and interact with the outside world, across distances. This wider connectivity would require solutions that aggregate traffic from that home network, or what I call the sub-access network, and direct that traffic into a wide area network. One possibility would be to use special gateway systems to bring that traffic into the broadband wireless packet data network for transmission across distances. This solution would have a major impact on broadband wireless networks, however, because while the data from individual devices would be very small, the deployment of tens of billions of these devices everywhere would likely create tremendous volumes of new wireless traffic.

And, of course, there will be the challenge of making it all robust, highly reliable, and secure – areas where Nortel has traditionally led the industry.

Networked appliances have been talked about for several years. What's different now?

We've seen some significant advances in wireless technology recently. For example, high-speed wireless devices and chips are reaching a high level of integration and miniaturization, enabling them to be easily and inexpensively embedded into various appliances. With advances in nanotechnology, devices will continue to shrink. In fact, a team of engineers from the University of Alberta (Canada), the National Institute for Nanotechnology (Alberta, Canada), and the University of Liverpool (U.K.) recently designed and tested the world's smallest transistor – the size of a single molecule.

As well, radio devices are commonly implemented using standard silicon technologies now, making possible very high densities and small sizes at very low power levels. As these wireless technologies have matured, they have become less expensive, leading to more widespread adoption. We are already seeing examples of this trend in wireless LANs, wireless multimedia components, and wireless sensors.

With respect to these new wireless spaces – the embedded networks, home networks, and sensor networks that you talked about – what is happening in the industry at large?

Several technologies and standardization initiatives are coming into play now, most of them focused on low-power short-range communications for sensor networks and home multimedia networks.

For sensor networks, for example, one wireless technology that is becoming well established is called Zigbee. Zigbee devices operate at relatively low bit rates (hundreds of kilobits per second) over short distances (tens of meters). They are extremely small, very power efficient, and inexpensive. This technology has broad industry support and is being promoted by the Zigbee Alliance, a worldwide association of some 150 different companies.

On the home multimedia networking front, there are several initiatives that are exploiting ultra wide band (UWB) wireless technology. UWB devices operate at very high data rates (400 to 1,000 megabits per second) over fairly short distances (1 to 30 meters). Industry consortiums like the WiMedia Alliance are adapting USB and Firewire protocols prevalent in today's PC industry so that they can operate over UWB, creating wireless USB and wireless Firewire standards for use as next-generation cable replacement technologies beyond Bluetooth.

The Digital Living Networking Alliance (DLNA) is another global cross-industry organization of leading companies in consumer electronics, computing, and mobile devices that began in June 2003. The DLNA, of which Nortel is a member, is working on standards for the interworking of various multimedia entertainment devices throughout the home at very high data rates. This group is also looking to exploit UWB technology as well as the next generation of wireless LAN technology – 802.11n – which also happens to be based on OFDM-MIMO (discussed in the article on page 24). UWB may be used to eliminate messy cabling problems in a "room area network" that interconnects components of your multimedia entertainment system, while 802.11n may be used to provide a backbone "home area network" for interconnecting the room area networks and other embedded devices.

How is the industry at large currently addressing the deployment of embedded networks outside the home?

For the most part, this is new territory. Although there have been some demonstrations of short-range sensor networking in limited applications, Nortel is exploring technologies for wide area embedded communications that would eliminate the range limitations of Zigbee and UWB to enable wireless communications over wider areas. This work is vital to the area of machine-to-machine communications, but the requirements are very different from the ones that have to date driven our consumer-oriented cellular networks.

These networks need to provide good in-building penetration and support a population of wireless devices that is several orders of magnitude larger than that found in a cellular network. In addition, these devices will tend to use short transactions with a few packets per transaction, rather than long sessions with the exchange of many packets. Although individual packets might be quite small in size, the volume of packets generated by such a large population will be enormous. For these wide area types of applications (such as smart metering in homes, and remote monitoring of patients outside hospitals), there is no

current standards activity. Nortel is looking to develop the technologies, and we will move those forward into standards when and as required.

Certainly low-power networks are among the new spaces for wireless, but what technology advances do you expect in the wireless core and access areas?

We expect a number of developments and innovations in these areas:

• *Continued advances in miniaturization* are the key to allow systems such as base stations to shrink to PC-size dimensions compared to today's much larger racks and equipment shelves. This miniaturization, combined with lower costs, will open new and more flexible avenues to deployment, where base stations, for example, can be easily mounted on the masthead next to the antenna rather than on a remote base station, as is the case today.

• *Advances in power amplifiers* will help to further lower costs. We are already leaders in this area, with multi-carrier linear power amplifier technology, as well as RF and digital integrated circuits that are enabling us to deliver the most compact low-cost solutions for cellular networks. We've developed a power amplifier that is 30-percent efficient (compared to today's 12-15 percent efficiency), and are currently developing a radically new technology that will lead to a 50-60 percent efficiency improvement.

• *Antenna technology innovation*, such as our OFDM-MIMO technology, will enable higher capacities at lower costs for large-throughput wireless systems. Coming next is the use of new materials, such as metamaterials, which we are developing in conjunction with the University of Toronto (Canada), to enable antennas to continue to shrink in size and cost.

• *MIMO technologies* for future link-based and collaborative MIMO systems will continue to lead to greater performance and simplicity. In this area, we have ongoing collaborative programs with the University of Waterloo (Ontario, Canada) and the Russian Academy of Science–MERA.

• *New security solutions* will address the challenges posed by machine-to-machine communications. Because each embedded wireless device will be responsible for defending itself, traditional security models in the wired world – which use special firewalls to control access at the edge of the network and centralized entities for authentication and validation – won't apply. The best way to establish trust and security in these ad-hoc embedded networks is currently an open research question. To answer this question, we have begun working with several university partners, including the WINLAB (Wireless Information Network Laboratory) cooperative research center at Rutgers University in New Jersey.

• *Innovations in spectral utilization* will make better use of the available spectrum. The amount of suitable spectrum is certainly finite, and we can't assume that large chunks of unused spectrum will be found. That's why many companies, including Nortel, are exploring more efficient ways to use the existing spectrum. Today, spectrum is allocated exclusively to individual services (such as fire, police, and cellular services) in a given region. But if you were to sample the spectrum being used in these bands, you would find that in the spectrum below 10 GHz, less than 3 percent is being used at any time. If these radio frequency bands could be shared among the various services and users, we could significantly increase spectrum utilization.

• *Cognitive radio technology* has the potential to give us much greater throughput and coverage, as well as increase spectrum utilization by ten times. With this technology, radios will "exercise judgement" to determine which slots of spectrum are available; which frequency, power level, transmission format, and protocol are required; and which mechanisms to use to avoid interference. We're pursuing this "cognitive" capability and in fact have introduced a rudimentary form of this capability for the U.S. market, on our Wireless Mesh Network solution. In the U.S., spectrum was recently allocated in the 5.5 to 5.85 GHz range (unlicensed band) for wireless LANs. Because this band is shared by military radar services, we had to build in the condition that all radar traffic must receive priority transmission, so that the radio can shift the wireless LAN traffic to a different frequency as soon as it receives a higher-priority radar signal.

What lies beyond the next five to ten years?

Things move so quickly, it's very difficult to predict. In the mid-1980s, we grappled with how to best deliver 8 kilobits per second voice to the mobile user. Twenty years later, nearly two billion mobile users in the world have access to wireless communications at speeds as high as 3 megabits or so per second. It is safe to say that wireless communications will continue to permeate every aspect of our lives and fundamentally enhance the way we communicate. There is much more room for technology innovation heading into the next decade and Nortel is very well positioned – having played a major role in shaping wireless technology for the past 20 years – to address the technology challenges in front of us. ■

*Nortel's **Al Javed,** most recently the Leader of the company's Wireless Advanced Technology program, will retire in September of this year. In his 28-year career with Nortel, Al played a key role in the development of innovations across all major wireless technologies, including in the areas of TDMA wireless systems, highly integrated wideband transceivers, advanced linear power amplifiers, smart antennas, and OFDM-MIMO for broadband wireless and wireless mesh networks. Until his retirement, Al continues to nurture the teams working on the next innovations for wireless technology.*