Wireless Data Networks: Reaching the Extra Mile

The demand for high-speed links has been continuing relentlessly over the past decade. While wireless networks have been evolving rapidly to meet this demand, they have been lagging behind the accelerated evolution common to wire-based networks. Meanwhile, as evolving technologies make wireless computing more attractive, the availability of bandwidth will become more and more of an issue.

While spectrum is getting less expensive, it is also getting more crowded, particularly at times of peak use. Currently, alternative carriers make their off-peak capacity available for reduced cost, or even for free, while the rates at peak time for these carriers are relatively expensive. As spectrum becomes more limited, users will be increasingly driven to use off-peak capacity, ultimately making it as saturated as the same spectrum at peak times. The net result of this trend is to push users to higher frequencies with higher device costs. These higher frequencies suffer from reduced signal propagation and penetration, which means higher overall system costs.

Another consideration in assessing bandwidth-bottleneck solutions is the requirement for real-time data services for many of the telemetry and control applications that will consume an increasing percentage of this bandwidth in the future. While voice applications are forgiving of noisy media, and non-real-time data transfer applications can wait for bandwidth to appear, real-time applications must have access on demand, which puts further pressure on the existing pool of spectrum.

The ultimate objective of wireless data communication is, of course, to use radio waves to interconnect end users in areas ranging in size from a few feet for desk area networks and to hundreds of feet for local area networks, and up to several miles for campus-wide and regional networks. The best solution to the spectrum saturation and bandwidth availability problem is to adopt technologies that make the most efficient use of existing spectrum through frequency reuse schemes, optimized signaling mechanisms, and scalable network architectures.

But if wireless networks are to be a truly viable technology they’ll need to be:

- ubiquitous, to support enough geographic coverage to provide seamless integration with existing wired networks;
- robust, to transfer multimedia information requiring data rates in the range of 10 to 20 Mbps;
- scalable, to accommodate the potentially high level of demand within the same geographic area of coverage;
- secure, to ensure confident use of the networks; and
- open, to facilitate competition among vendors for the benefit of the consumer.

In order to achieve these goals quickly, we’ll need to accelerate the development and implementation of a number of key technologies—such as spread spectrum multihopping—especially because wire users have grown accustomed to near-instantaneous response and the background noise level for wireless communications is already high.

THE SPECTRUM

The radio frequency (RF) spectrum is composed of licensed and unlicensed bands. Access to licensed bands is restricted to those organizations to which the licenses have been granted. As a result, solutions for these bands are typically dictated by the proprietary requirements of the licensees. Unlicensed bands, on the other hand, are regulated, but there is no restriction for access to such bands by any individual vendor or particular licensee. The market of unlicensed bands lends itself well to open solutions.

Spread spectrum techniques—one of the most viable techniques to exploit limited bandwidth—ensure reliable data communication in the presence of noise by using a larger bandwidth than what is necessary for the baseband signal. Currently, there are two different technologies used in spread spectrum technology:
An Overview of Wireless Technology

Analog cellular
By using analog cellular, modern-equipped PCs and laptops can transfer data over analog cellular telephone networks. The data rates supported are low—only a few Kbps—but due to the wide availability of modems and analog cellular services, analog cellular is the most dominant method for wireless data communications.

Digital cellular
As digital cellular telephone services are becoming available in more areas, so will wireless data communications using these services. There are different standards available for digital cellular, including Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), and Global System for Mobile Communication (GSM), but the effective transfer rate of digital cellular is not much higher than that of analog cellular.

Cellular digital packet data
Cellular Digital Packet Data (CDPD) is a method that inserts digital data traffic into analog cellular telephone communications. The technology employs unused analog channels available in the analog telephone cellular infrastructure. Transmitters use a channel for a short transmission burst and release the channel for analog voice links. The effective data rate that can be achieved using this technique is 19.2 Kbps, but the technology suffers from the risk of competing with analog cellular voice traffic, which has a higher priority over CDPD.

Mobile radio networks
Similar to cellular telephone networks, which are geared toward individual users, Specialized Mobile Radio (SMR) and Extended Specialized Mobile Radio (ESMR) were introduced in the US for utility, dispatch, and other service-oriented metropolitan area users. The SMR and ESMR technology employs narrow bands and hence have limited data rates somewhere below 20 Kbps.

Personal Communications Services
Personal Communications Services (PCS) is a new technology currently being deployed globally to serve LANs, MANs, and WANs. Low-tier PCS is an evolutionary trend toward microcell coverage for frequency reuse and low-power benefits. High-tier PCS is used for early digital cellular systems such as GSM, TDMA, and CDMA, all of which are characterized by complex modulation schemes and large macrocells on the order of 0.5 to 3.0 kilometers. PCS technologies offer greater network complexity and lower end-to-end latency but consume more power than other methods.

Satellite
Three different satellite-based PCS networks are currently being proposed and implemented, namely geosynchronous orbit (GEO), Medium Earth Orbit (MEO), and Low-Earth Orbit (LEO) technologies, all of which are intended to offer wireless data services at relatively low data rates, below 64 Kbps.

Industrial, scientific, and medical networks
Industrial, Scientific, and Medical (ISM) networks offer higher data rates—up to 100 Kbps—and are exclusively used for wireless data communications and networking. Most of the ISM networks operate in the unlicensed 902- to 928-MHz band, but many vendors have plans to move into the higher 2.4-GHz band.

Microwave links
For many years, microwave analog and digital point-to-point communications have been used to carry telephone traffic as well as data. Microwave links operate in higher frequency bands than any of the other technologies and offer data rates of several Mbps.

Multipoint distribution systems
Local Multipoint Distribution Systems (LMDS) is a point-to-multipoint technology running in the 28-GHz band with 1.3 GHz of spectrum allocated to it in Canada. LMDS uses spread spectrum and microcell technology that supports two-way data transfer rates up to 1 Gbps. One drawback is that signal propagation at the 28-GHz range requires a line-of-sight path between transmitter and receiver. Multi LMDS is a one-way technology with 200 MHz of bandwidth spectrum that is being created for broadcast applications.

Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS).

FHSS
FHSS uses a number of frequency channels, with the transmitter sending data over one channel for a short period of time, then randomly hopping to another channel. By hopping around channels, the transmitter can avoid getting stuck with a noisy channel. The receiver, meanwhile, has to follow the same random walk among the channels. Such spreading of signal bandwidth does not require a single contiguous block of RF band. FHSS

- does not require a contiguous band of frequency spectrum;
- is simple to implement, since it employs narrow-band signaling techniques;
- is cheaper to implement than DSSS; but
- presents difficulties in coordinating hand-over between adjacent cells for mobile users.

DSSS
DSSS, on the other hand, takes a baseband digital signal and replaces the transmission of ones and zeros with codes of fixed length. Consequently, the bandwidth is spread by a large factor. The receiver uses the same code the transmitter uses and, through correlation, can detect the transmitted signal even when it is buried in noise. DSSS

- requires a contiguous band of frequency spectrum,
- offers over 50 percent additional geographic coverage over FHSS for the same radiated power,
- offers better signal quality than FHSS for the
ultimately, DSSS offers a better choice of technology than FHSS for reaching longer distances and delivering higher data rates. But fundamental spread spectrum technology common to FHSS and DSSS will become one of the most viable techniques for enabling independent signals to share a single spectrum band.

**Multihop Networks**

In most wireless network environments, the radio channel is used to connect the mobile terminal to a base station in a single hop. The base station itself is connected to a wired infrastructure. Consider a system where there is no wired infrastructure yet connectivity must be maintained among users who can move around arbitrarily and can at times not be in direct transmission range of each other.

In such a system, multihop-capable communications become extremely important, especially because, due to transmitted power constraints, not all radios are within range of each other, and packets may need to be relayed from one radio to another on their way to their intended destinations. One reason for advocating multihopping technology is that by carefully limiting the power of radios, we conserve battery power. Furthermore, we also cause less interference to other transmissions farther away, which gives the additional benefit of reusing channel spectrum (and thereby increasing the capacity of the system).

Instant infrastructure systems are more complex to design and manage than traditional single-hop, centrally controlled systems, especially because—to be truly viable—the salient features of a fully implemented multihopping system would have to include complete support for multimedia and mobility. While some systems have combined any two of these technologies, no system has successfully integrated all three.

For example, real-time multimedia capabilities using multihop technology have been implemented in certain Iridium satellite systems and in the ground based Metricom network that supports voice and data services. Real-time multimedia systems that support mobility are pervasive in cellular radio. An example is Berkeley’s Bay Area Research Wireless Network (BARWAN) Project, which employs dynamic handoffs with “hints” for multimedia, mobile, cellular networks. Finally, multihop technology that includes mobile capabilities was developed as early as the 1970s ARPA packet radio project.

It is the three-way combination of these features—multimedia, multihopping, and mobility—which proves to be particularly difficult, but will be essential for the future of wireless computing.

In the near future, networks that provide low-cost communications services with very low access costs will make wireless technology solutions widely available. Such networks will be used extensively in applications that lend themselves to telemetry and monitoring service models. Applications that fit into these models tend to have low average bandwidth requirements and a high tolerance of latency, with occasional bursts of high-priority latency-sensitive communications activity.

Examples of such applications include automatic meter reading, equipment monitoring, and vehicle location tracking. The key to the future growth of such services is the technical and financial ease with which position-independent status monitoring and data collection can be integrated into devices and distributed systems of any type. Moving in this direction has not been easy, but has been aided by industry-wide efforts, including the IEEE Working Group for Wireless LANs, which on June 26, 1997, passed the 802.11 standard for multihopping WLANs operating in the 2-GHz band.

Another barrier to widespread acceptance of wireless communications as a primary communications medium is the lack of interoperability between vendors and service providers. Currently, all wireless networks operating at the scope of a metropolitan area are proprietary, both at the lower protocol layers and at the more critical applications interface and management layers. This forces a client to use a single service provider in implementing an application-specific wireless communications network, compromising their mobility and coverage unnecessarily. Presumably, customers would much prefer to plug their devices into a wireless network that spanned vendor systems and service providers transparently, thereby reducing or eliminating dependencies on provider coverage areas or network access device characteristics.

As wireless data solutions are deployed more extensively, the dependence on them will increase, leading to continued pressure to improve coverage and level of service. To meet this increasing demand, new network solutions must be designed for high reliability and availability. An atmosphere of interdependence among service providers and vendors must prevail. It is especially important to develop open solutions for wireless networks. The unlicensed bands seem to be the most appropriate place for such solutions. Furthermore, uniform channel sharing using classical time-division multiple access (TDMA), frequency-division multiple access (FDMA), or code-division multiple access (CDMA) is efficient for continuous, persistent loads, such as voice and video links, but not for bursty computer loads. In order for a radio channel to be used efficiently, the chan-
may improve performance significantly and might be the best method to ensure that wireless networks become a truly viable data communications solution.

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