Wireless Communications

Rembrandt Wireless

The cellular digital packet data (CDPD) system is a wide area wireless data service layed on the analog cellular telephone network. CDPD shares the FDMA voice cha of the analog systems, since many of these channels are idle owing to the growth of tal cellular. The CDPD service provides packet data transmission at rates of 19.2 kbp is available throughout the United States. However, since newer generations of cellula tems also provide data services and at higher data rates, CDPD is mostly being replac these newer services. Thus, wide area wireless data services have not been very succe although emerging systems that offer broadband access may have more appeal.

1.4.5 Broadband Wireless Access

Broadband wireless access provides high-rate wireless communications between a fix cess point and multiple terminals. These systems were initially proposed to support in tive video service to the home, but the application emphasis then shifted to providing high-speed data access (tens of Mbps) to the Internet and the World Wide Web as w high-speed data networks for homes and businesses. In the United States, two freq bands were set aside for these systems: part of the 28-GHz spectrum for local distril systems (local multipoint distribution service, LMDS) and a band in the 2-GHz spe for metropolitan distribution service (multichannel multipoint distribution services, MN LMDS represents a quick means for new service providers to enter the already stiff co tition among wireless and wireline broadband service providers [5, Chap. 2.3]. MM a television and telecommunication delivery system with transmission ranges of 30–5 [5, Chap. 11.11]. MMDS has the capability of delivering more than a hundred digital TV channels along with telephony and access to the Internet. MMDS will compete n with existing cable and satellite systems. Europe is developing a standard similar to M called Hiperaccess.

WiMax is an emerging broadband wireless technology based on the IEEE 802.16 sta [16; 17]. The core 802.16 specification is a standard for broadband wireless access sy operating at radio frequencies between 2 GHz and 11 GHz for non–line-of-sight oper and between 10 GHz and 66 GHz for line-of-sight operation. Data rates of around 40 will be available for fixed users and 15 Mbps for mobile users, with a range of several meters. Many manufacturers of laptops and PDAs (personal digital assistants) are pla to incorporate WiMax once it becomes available to satisfy demand for constant Intern cess and email exchange from any location. WiMax will compete with wireless LAN cellular services, and possibly wireline services like cable and DSL (digital subscriber The ability of WiMax to challenge or supplant these systems will depend on its relativ formance and cost, which remain to be seen.

1.4.6 Paging Systems

Paging systems broadcast a short paging message simultaneously from many tall bas tions or satellites transmitting at very high power (hundreds of watts to kilowatts). Sy with terrestrial transmitters are typically localized to a particular geographic area, suc city or metropolitan region, while geosynchronous satellite transmitters provide natio international coverage. In both types of systems, no location management or routing tions are needed because the paging message is broadcast over the entire coverage area high complexity and power of the paging transmitters allows low-complexity, low-p pocket paging receivers capable of long usage times from small and lightweight bat In addition, the high transmit power allows paging signals to easily penetrate building Paging service also costs less than cellular service, both for the initial device and f monthly usage charge, although this price advantage has declined considerably in years as cellular prices dropped. The low cost, small and lightweight handsets, long b life, and ability of paging devices to work almost anywhere indoors or outdoors are the reasons for their appeal.

Early radio paging systems were analog 1-bit messages signaling a user that sor was trying to reach him or her. These systems required callback over a landline tele to obtain the phone number of the paging party. The system evolved to allow a shor tal message, including a phone number and brief text, to be sent to the pagee as well. paging systems were initially extremely successful, with a peak of 50 million subsc in the United States alone. However, their popularity began to wane with the wides penetration and competitive cost of cellular telephone systems. Eventually the comp from cellular phones forced paging systems to provide new capabilities. Some implem "answer-back" capability (i.e., two-way communication). This required a major cha design of the pager because now it needed to transmit signals in addition to receiving and the transmission distance to a satellite or base station can be very large. Paging panies also teamed up with palmtop computer makers to incorporate paging function these devices [18]. Despite these developments, the market for paging devices has s considerably, although there is still a niche market among doctors and other profess who must be reachable anywhere.

1.4.7 Satellite Networks

Commercial satellite systems are another major component of the wireless communic infrastructure [2; 3]. Geosynchronous systems include Inmarsat and OmniTRACS. Th mer is geared mainly for analog voice transmission from remote locations. For exampl commonly used by journalists to provide live reporting from war zones. The first-gene Inmarsat-A system was designed for large (1-m parabolic dish antenna) and rather e sive terminals. Newer generations of Inmarsats use digital techniques to enable sn less expensive terminals, about the size of a briefcase. Qualcomm's OmniTRACS pr two-way communications as well as location positioning. The system is used primari alphanumeric messaging and location tracking of trucking fleets. There are several difficulties in providing voice and data services over geosynchronous satellites. It t great deal of power to reach these satellites, so handsets are typically large and bulky. dition, there is a large round-trip propagation delay; this delay is quite noticeable in tw voice communication. Geosynchronous satellites also have fairly low data rates of les 10 kbps. For these reasons, lower-orbit LEO satellites were thought to be a better mat voice and data communications.

LEO systems require approximately 30–80 satellites to provide global coverag plans for deploying such constellations were widespread in the late 1990s. One of the ambitious of these systems, the Iridium constellation, was launched at that time. Hov the cost to build, launch, and maintain these satellites is much higher than costs for tern base stations. Although these LEO systems can certainly complement terrestrial syste low-population areas and are also appealing to travelers desiring just one handset and separating the cooperating nodes. When there is less of a difference between the sepa of the cooperating nodes and the transmission distance between these clusters, the e cost required for the local exchange of information exceeds the energy benefits of co ating. Cooperative MIMO is one form of cooperative diversity. Others were discus: Section 16.3.3, and these other techniques may provide energy savings comparable to ceeding those of cooperative MIMO, depending on the network topology.

16.6.3 Access, Routing, and Sleeping

Random access schemes can be made more energy efficient by (i) minimizing collisio the resulting retransmissions and (ii) optimizing transmit power to the minimum rec for successful transmission. One way to reduce collisions is to increase error protect collisions become more frequent [111]. Alternatively, adaptively minimizing power th probing as part of the random access protocol has been shown to significantly increase e efficiency [111; 38]. Another method for energy-efficient access is to formulate the d uted access problem using a game-theoretic approach, where energy and delay are associated with the game [112]. Several different approaches to energy-efficient access evaluated in [113]. However, no clear winner emerged because the performance of eac tocol is highly dependent on channel characteristics. Delay and fairness constraints ca be incorporated into an energy-efficient access framework, as investigated in [114]. M: these techniques avoid collisions through a version of TDMA, although setting up ch: ized access under distributed control can lead to large delays.

If users have long strings of packets or a continuous stream of data, then random a works poorly since most transmissions result in collisions. Hence channels must be ass to users in a more systematic fashion by transmission scheduling. Energy constraints new wrinkle to scheduling optimization. In [100] it was shown that the energy requi send a bit is minimized by transmitting it over all available bandwidth and time dimen However, when multiple users wish to access the channel, the system time and band resources must be shared among all users. More recent work has investigated optimal s uling algorithms to minimize transmit energy for multiple users sharing a channel [11 this work, scheduling was optimized to minimize the transmission energy required by user subject to a deadline or delay constraint. The energy minimization was based on ciously varying packet transmission time (and corresponding energy consumption) to the delay constraints of the data. This scheme was shown to be significantly more e efficient than a deterministic schedule with the same deadline constraint.

Energy-constrained networks also require routing protocols that optimize routes re to energy consumption. If the rate of energy consumption is not evenly distributed acr nodes then some nodes may expire sooner than others, leading to a partitioning of th work. Routing can be optimized to minimize end-to-end energy consumption by app the standard optimization procedure described in Section 16.3.3, with energy per hop (in of congestion or delay) as the hop cost [116]. Alternatively, the routes can be computed on costs associated with the batteries in each node – for example, maximizing the mini battery lifetime across all nodes in the network [116; 117]. Different cost functions to mize energy-constrained routing were evaluated via simulation in [116] and were all ro equivalent. The cost function can also be extended to include the traditional metric of along with energy [118]. This method allows the route optimization to trade off betwe lay and energy consumption through different weighting of their respective contribut the overall cost function. Note that computation and dissemination of routing tables c tail significant cost: this can be avoided by routing traffic geographically (i.e., in the g direction of its destination), which requires little advance computation [119].

Energy-constrained nodes consume significant power even in standby mode, whe are just passive participants in the network with minimal exchange of data to maintai network status. The paging industry developed a solution to this problem several decad by scheduling "sleep" periods for pagers. The basic idea is that each pager need only for transmissions during certain short periods of time. This is a simple solution to impl when a central controller is available, but it is less obvious how to implement such stra within the framework of distributed network control. Sleep decisions must take into ac network connectivity, so it follows that these decisions are local but not autonomous. M anisms that support such decisions can be based on neighbor discovery coupled with means for ordering decisions within the neighborhood. In a given area, the opportu sleep should be circulated among the nodes, ensuring that connectivity is not lost th the coincidence of several simultaneous decisions to sleep.

16.6.4 Cross-Layer Design under Energy Constraints

The unique attributes of energy-constrained networks make them prime candidates for layer design. If node batteries cannot be recharged, then each node can transmit only a number of bits before it dies, after which time it is no longer available to perform its int function (e.g. sensing) or to participate in network activities such as routing. Thus, e must be used judiciously across all layers of the protocol stack in order to prolong ne lifetime and meet application requirements.

Energy efficiency at all layers of the protocol stack typically imposes trade-offs be energy consumption, delay, and throughput [120]. However, at any given layer, the op operating point on this trade-off curve must be driven by considerations at higher layer example, if a node transmits slowly then it conserves transmit energy, but this compl access for other nodes and increases end-to-end delay. A routing protocol may use trally located node for energy-efficient routing, but this will increase congestion and on that route and also burn up that node's battery energy quickly, thereby removing it the network. Ultimately the trade-offs between energy, delay, throughput, and node/ne lifetime must be optimized relative to the application requirements. An emergency r operation needs on-the-scene information quickly, but typically the network supportin local information exchange need only last a few hours or days. In contrast, a sensor ne embedded into the concrete of a bridge to measure stress and strain must last decades, t the information need only be collected every day or week.

16.6.5 Capacity per Unit Energy

When transmit energy is constrained, it is not possible to transmit any finite number c with asymptotically small error probability. This is easy to see intuitively by consic the transmission of a single bit. The only way to ensure that two different values in space (representing the two possible bit values) can be decoded with arbitrarily small

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