System Aspects of Cellular Radio

The greatest single factor in enhancing spectral efficiency of a network is not complex multiple access techniques, efficient speech and channel coding, modulation, powerful protocols, etc., but the mass deployment of microcells. By this simple technique we can repeatedly and efficiently reuse the precious spectrum.

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Public cellular radio systems are less than two decades old. The concepts of cellular radio are much older, rooted in the '40s, when technology was far too immature to support such complex systems. There are two main components in mobile radio systems. The radio interface, which allows users to wander while communicating via radio from a mobile station (MS) to the other component, a fixed network that interworks with the public switched telephone network (PSTN) or the integrated services digital network (ISDN). Private mobile radio communication systems have been present throughout most of this century, as exemplified by the marine, police, and military services. What makes public cellular radio complex is the control structure that enables the network to know where an MS is currently located, and to track it irrespective of whether the MS is making a call, with the proviso that the mobile equipment is switched on. The control mechanism is made possible by a set of protocols that enables MSs to register on the network, facilitates call set-up and clear-down, switches MSs between base stations (BSs) as they travel, controls the radiated power levels, provides security (in some systems), and perform a myriad of other vital functions.

However, the number of users a network can support is fundamentally dependent on the common air interface (CAI) over which users communicate. User capacity is dependent on many factors, but the cardinal ones are the amount of spectrum the regulators allocate, the size of the radio coverage area from a BS, and the amount of interference a particular radio link can tolerate.

In this article we are primarily concerned with the system aspects associated with the CAI. We do not consider the subsystem of the radio link, such as speech codecs, channel codecs, modems, nor propagation issues. Multiple access methods that enable many users to access the network are of interest, but we refrain from in-depth discussions of the two major multiple access methods currently in vogue as they are considered in other articles in this issue. We will focus on the critical importance of BS siting. Starting with existing large cells, we will deliberate on the problems that might arise in siting BSs in three dimensional microcells, in order to consider suitable multiple access methods for future cellular environments. In keeping with this magazine, our treatment will be general and light in touch, identifying issues rather than solving them.

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System Planning in First- and Second-Generation Systems

Cell Clusters

A network operator on purchasing the equipment for a particular system is primarily concerned with how and where to site the BSs, how to manage their use of scarce radio spectrum, and how to optimize the teletraffic for the equipment deployed. System planning depends on many factors, and we will commence by considering a cellular network using either frequency division multiple access (FDMA), or a combination of time division multiple access (TDMA) and FDMA. In a later section, we will discuss code division multiple access (CDMA) systems.

Each BS transceives with a number of mobiles residing within its radio coverage area. This area is referred to as a cell. BSs are deployed so that cells partially overlap with other cells in the vicinity of their boundaries, as shown in Fig. 1. Suppose a mobile commences a call at position S in cell C, follows the route shown dotted, and terminates the call at position F in cell B. At some point within the overlap or handover region (shown shaded) the received signal level at the mobile will be below a system threshold and lower than the received signal level from BS_B. Signaling between the mobile, the BSs, and control centers results in the instruction that communications with the mobile to be handled by BS_B to maintain call quality.

Cells are arranged in clusters, and often each cluster uses the entire allocated spectrum. The clusters are tesselated so that the limited spectrum is repeatedly reused over large geographical areas, with each cluster supporting the same number of

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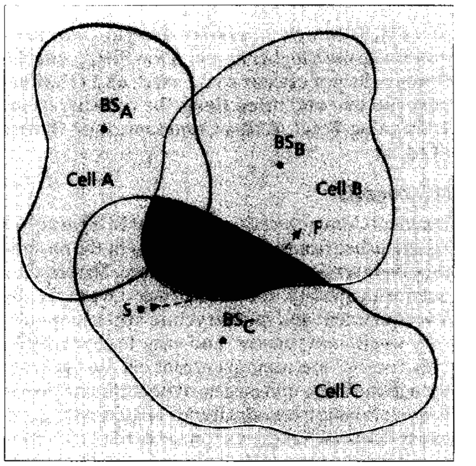
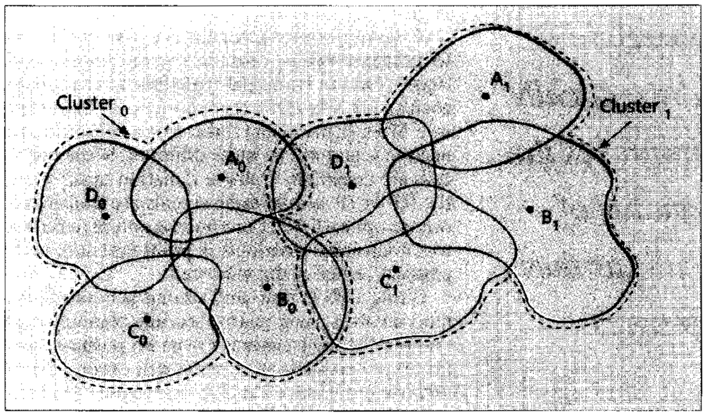
users. Figure 2 shows two four-cell clusters where cells A_0, B_0, C_0, and D_0 form $cluster_0$, and cells A_1, B_1, C_1, and D_1 are in $cluster_1$. Cells A_0 and A_1 are assigned the same set of channels which are, say, a quarter of all the available channels. Similar comments apply to B_0 and B_1, C_0, and C_1 and D_0 and D_1. Observe that mobiles in cells A_0 and A_1 use the same channels, and consequently they may interfere with each other. This cochannel interference is contained to acceptable limits by the distance between the cells. As a mobile travels from one cell to another, which may be in a different cluster, it is assigned a different channel, which also means a different carrier frequency. It is important to observe that as the cluster uses all the available channels, then if the cell sizes are decreased which causes a corresponding reduction in cluster size, the number of channels per unit area increases. The most effective way of increasing network capacity is to decrease the cell size, although the complexity of the network infrastructure increases.

The capacity of a network also depends on the number of cells per cluster, and the fewer the cells per cluster the greater the capacity. This is because with fewer cells more bandwidth can be made available at each BS, and therefore more channels can be deployed at each BS. The teletraffic in Erlangs is non-linearly related to the number of channels at a BS, and a disproportionate increase in teletraffic is obtainable for a given increase in the number of BS channels.



■ **Figure 1**. *Overlapping cells with mobile travelling from S to F.*



■ **Figure 2**. *Two cluster of cells with four cells per cluster.*

Growth Scenarios

In the start-up phase of a cellular network, capacity is not the problem as there are hardly any users. However, the designer must provide coverage. BSs are sited according to the maximum range that can be accommodated. This range depends on the physical characteristics of the environment, the propagation frequency, the antenna gain, and the characteristics of the specific equipment to be deployed. As capacity is of no importance at this stage, large cluster sizes are used, as this provides negligible cochannel interference. This interference is from mobiles in neighboring clusters using the same channel.

As the network matures, capacity becomes increasingly important. Cluster size is decreased while maintaining signal-to-interference ratios (SIRs) that ensure that link quality is acceptable. In first- and second-generation systems, e.g., the American analog Advance Mobile Phone System (AMPS) and the European digital Global System of Mobile communications (GSM), respectively, large cells are often used. These cells have antennas located on the tops of tall buildings where rental charges may be high. To avoid renting additional BS sites, and to accommodate terrain and building variations, omni-directional antennas are replaced by directional ones that partition the cells into sectors. Sectorization generally results in an increase in SIR, which improves the quality of the radio transmissions. If the sectorization is not done without changing the cluster size, then each BS site has the same number of channels. Suppose each cell is divided into three sectors, and hence the channels in each sector is one-third of the total site channels. For the same acceptable blocking probability the traffic carried by the site is three times the traffic carried in each sector, and this is less than the traffic carried by the original cell before sectorization. This diminution of carried traffic may be readily verified by consulting the Erlang-B traffic tables. Now, if the cluster size is also decreased when sectorization is introduced, the carried traffic is increased. This occurs because with a decrease in cluster size the number of channels per site significantly increases. For example, changing from a 7-cell omnicluster to a 4-cell cluster with three sectors per cell will provide a gain in carried traffic of < 1.75.

The minimum acceptable SIR (denoted by SIR_{min}) is system-specific. For example, in the simple FDMA networks, the average SIR is required to be approximately 18 dB in multipath fading. By using discontinuous transmission (DTX), which means transmission stops while a user is not speaking, frequency hopping (FH) of the carriers, and power control whereby the transmitter power is restrained to provide only sufficient received power to ensure acceptable link quality, such systems can allow lower SIR_{min}. Digital TDMA systems include additional techniques such as coding, interleaving, and frequency hopping to achieve further improvements. For example, it is believed that a GSM systems can be designed with SIR_{min}

Transmitter power control decreases the interference that one or a few users cause to others and thereby dramatically improves the quality of calls as they progress.

of 9 dB, although a network designer would be prudent to use a higher figure. A low SIR_{min} enables fewer cells per cluster to be used, and GSM has between two and three times the capacity of the UK analog Total Access Communication System (TACS).

Microcells

Personal Communications Systems (PCS) are often distinguished from cellular telephony by the promise to provide service to anyone, anywhere. The required network capacity, the ubiquitous coverage, and low equipment and infrastructure cost will require very small, inexpensive, and easy-to-deploy BSs. "Microcells" are used in current cellular systems, though their size and cost must be further reduced. Base stations are very small and inexpensive in cordless systems such as the European cordless telecommunications system (CT-2) and the digital European cordless telecommunications system (DECT), but they were not designed for cellular networks nor do they provide the high capacity required for PCS.

Conventional macrocells are interconnected to mobile switching centers typically in a star configuration via standard transmission facilities, such as 1.5 Mb/s (North-American TI Standard) or 2 Mb/s (European) links. Microcell interconnection is and will be quite different. Some microcells are essentially "remote radiation sites," where the RF or IF mobile radio signals are transmitted over an optical link [1], or a point-to-point radio link, to a microwave distribution point that acts as the physical center of the microcell.

Siting a BS in first- and second-generation systems involves using relatively crude planning tools that predict radio coverage from BS positions with errors in pathloss that often will exceed 20 dB and usually require supporting propagation measurements, and finding property owners who will allow their properties to be rented for the deployment of BSs. Prediction planning tools for street microcells are more accurate, on the proviso that the BS antenna are mounted below the urban sky-line. The microwave propagation in microcells is essentially determined by the topology of the streets and their buildings, and therefore microcells are irregular if streets are irregular. Figure 3 shows path loss contours for a microcellular BS in Central London predicted using MIDAS.[1]

Mixtures of Cells

There are many types of cells whose size and shape are determined by the radiated power levels, the antenna location, and the neighboring physical environment [2]. We have just described how the street microcell is determined by the surrounding street topologies and buildings. As we raise the height of the BS antenna until it clears the tops of some of the lower buildings, we form minicells. Placing the BS on the top of the locally tallest buildings yields macrocells. Nodal cells provide a high-capacity radio network node [3], a type of telepoint cell. We can arrange picocells of a few meters diameter, e.g., a room in a building, to large rural cells, to megacells, to the large satellite cells (> 500 km) [2, 3]. We may anticipate that cells will be geographically mixed and overlaid.

Having cellular systems with multidimensional, multilayered, and multisized cells will profoundly compound the complexities of frequency planning. Bandwidth partitioning can be adopted. For example, microcells could be given the majority of the bandwidth as they are able to operate with very high capacity and will support the greatest variety of services. The oversailing macrocells will be used merely to cope with radio deadspots within the microcellular network and to support handovers. They could also be used for vehicular mobiles. The macrocells could use a different frequency band from the street microcells. Office microcells could have a unique band to prevent them from interfering with mobiles in street microcells, but there will be difficulties in providing good frequency planning for office microcells in adjacent buildings and within buildings. There is a serious disadvantage in the bandwidth partitioning approach and that is a decrease in the overall carried traffic. We will consider dynamic channel allocation methods to alleviate frequency planning difficulties in a section to follow.

Handover Issues in FDMA and TDMA Systems

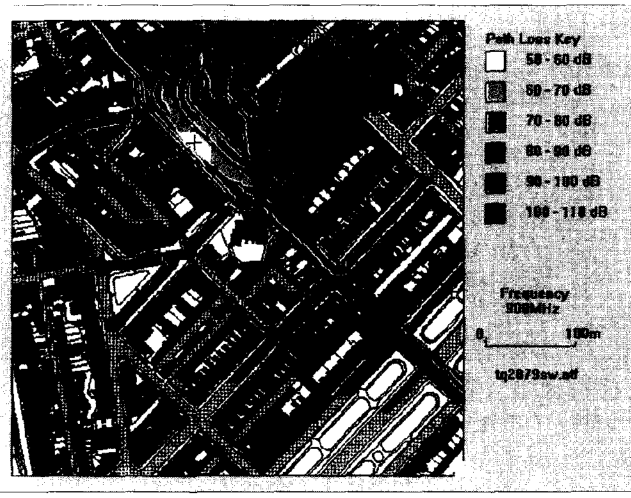
Handover (HO), or handoff, is the switching procedure when a MS changes its communication from one BS to an adjacent one when the received signal decreases below a system threshold [4]. There are two main types of handover. There is the hard handover (HHO) where the communications of a MS with a BS are severed before they are re-established with the new BS; a break-before-make arrangement. The other is a soft handover (SHO), where both the existing BS and the BS that will ultimately assume responsibility for the call communicate simultaneously with the MS providing a form of maximal ratio combining diversity at the mobile, and selection diversity at the network end [5]. HHOs are commonly used in FDMA and TDMA, while SHOs are used in CDMA. SHOs have the virtue of enhancing link quality where it is needed most, namely at the cell boundaries.

Preparing for an HO can be a complex procedure. First, the decision when and where to HO must be made, and then both the handset and the network must switch. The decision algorithm typically uses measurements of received signal strength indication (RSSI) and bit error rate (BER) to detect the need to HO and must identify a free channel in a neighboring cell. There are thresholds for RSSI and BER, and hysteresis and system timers may be used to preclude a MS making repeated HHOs in TDMA. There are a number of prioritized HO schemes. Some aim to minimize both the probability of forced termination of calls in progress due to HO failures, and the degradation in spectrum utilization. For example, channels can be reserved for HOs, and algorithms for managing such reservations have been adapted from wired telephony applications. Other HO features aim at balancing or dissipating the teletraffic load across neighboring cells. For example, when the teletraffic loading exceeds a predetermined threshold, some calls are handed over to adjacent cells to balance the carried teletraffic. Often oversailing cells will be used to assist smaller cells, which temporarily have no

[1] *A proprietary microcellular prediction planning tool from Multiple Access Communications Ltd.*

free channels for HHO. This procedure enables the smaller cells to operate with high channel utilization, increasing the probability of blocking knowing that an oversailing cell is available to provide HHOs when needed [6].

Current cellular systems generally use hierarchical switching networks and must perform a "hot switch" at the time of handoff. Non-hierarchical and packet switching networks, though, offer flexibility and ease of deployment and will appear more and more in third-generation systems. For example, if the BSs are linked to an optical local area network (LAN) then HHOs merely require directing packets to adjacent BSs and letting the MS communicate with the BS that can provide the better link. Packets can now be rapidly redirected with no load on the main network and also achieve HHO diversity [7].



■ **Figure 3.** *Path loss contours for a microcellular BS in Central London.*

DCA in FDMA and TDMA Systems

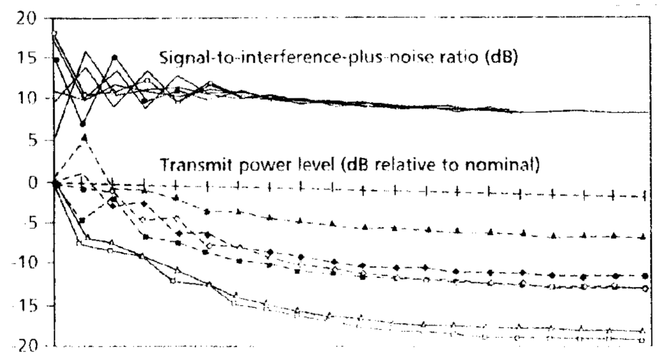
Dynamic Channel Assignment (DCA) can in principle operate with FDMA or TDMA, and with only modest enhancements to second-generation CAIs. So far we have been discussing fixed channel allocation (FCA) where specific channels in a TDMA or FDMA system are assigned to each BS. With DCA there is no fixed relationship between the cells and the channels that they use. Each BS may have all the channels allocated to the entire cluster, and deploy them in an optimum way, implementing fast HOs for a particular mobile when the path loss becomes too large or when the SIR value drops below a system threshold. With DCA there is no frequency planning but BSs must be sited to ensure there is contiguous coverage. Algorithms are used that select the appropriate carriers and time slots to yield significant capacity gains compared to the FCA arrangements described previously. We observe that DCA even allows some frequency reuse among sectors of the same cell. The cordless telecommunications (CT) systems CT2 and DECT system both use a basic form of DCA.

The assignment of channels may be done by a system that adapts to both the traffic loading at the BS and the interference on the channels. In a traffic-adaptive system each cell site examines channel usage in neighboring cells and others that might interfere, and avoids those channels when assigning a channel to a new user. A particularly simple system is *channel borrowing*, in which a fixed channel assignment is generally followed, but when a cell is overloaded it can use idle channels belonging to a neighbor's fixed allocation. Another method is *Markov allocation*, which assigns to each new call the first un-used and non-interfered channel in an order specific to the corresponding cell-site. The orderings are jointly optimized based on the specific interference relationships among the cells and their traffic levels [8]. Regardless of the algorithm, communication of channel usage information among cells or to a central controller is required.

In contrast, the interference-adaptive system lends itself to distributed DCA algorithms that are able to self-organize. The MS (and perhaps its BS) controls the channel assignment of a call without the need to communicate with other BSs or with a central controller. At the time of a new call or an HHO request the interference is measured in a subset of the channels. A channel is then assigned if it can offer an adequate SIR. The choice among acceptable channels is an important issue: choosing the least-interfered channel provides most robust quality, while selection according a pre-defined order may lead to greater capacity [9]. If no channel is found the call is blocked, queued, or dropped. Assuming an appropriate channel is assigned, the interference continues to be measured and HHO is once more initiated if the SIR becomes too low, and so on.

An efficient arrangement is to use inactive timeslots for interference monitoring and to store the results for when a call re-assignment is necessary [10]. A MS and its BS may experience different SIRs on the same channel, and so measurements are made at both ends of the link. These measurements may include BER or frame error rate (FER) histories, received-power measurements of signal and interference separately, or signal-quality statistics derived from the demodulation process. Digital cellular systems all provide error-rate and power-level measurements, but the accuracy of the signal-quality measurements may nevertheless be poor. By specifying the SIR thresholds to be higher than the minimum required for good link quality, robustness against measurement and decision errors may be achieved.

Transmitter power control decreases the interference that one or a few users cause to others and thereby dramatically improves the quality of calls as they progress. A simple algorithm is for each user to increase its transmit power when the SIR is inadequate and to decrease the SIR when it is more than adequate, and this succeeds whenever there is any set of power levels that allow all the stations to achieve an adequate SIR. Such methods can be applied in FCA systems, and are particularly useful with interference-adaptive DCA. Figure 4 illustrates the operation of this algorithm where each of six users is trying to attain a signal-to-interference-plus-noise ratio (SINR) of 10 dB. At the start, with equal transmit powers, the users have widely varying SINR. After a few corrections, their per-



■ **Figure 4.** *Performance of distributed power control.*

formance is about equal, and they all gradually decrease their transmit power until the noise floor limits their performance to the target level.

The capacity of interference-adaptive DCA has eluded precise analysis, but as in CDMA the reduction in the margin of SIR needed to protect "worst-case" calls yields significant gains in capacity compared to FCA and traffic-adaptive DCA. Simulation studies have shown that simple, distributed interference-adaptive DCA enjoys several-fold capacity gains compared to FCA. Figure 5 shows representative results [13]. The curves show the loads that can be supported, with equivalent voice quality, by FCA and DCA if a total of 108 channels are available. From left to right, when P(block) is 1 percent, we see first that FCA with 3 channel sets can support 25 Erlangs per cell. Then DCA improves capacity to 40 Erlangs, with the same voice quality, and DCA with power control provides 65 Erlangs. Rightmost, an upper bound: if all 108 channels were available in every cell without restriction, the capacity would be 90 erlangs.

Power control greatly enhances performance, and the DCA process need not cause unacceptable channel reassignment or call-failure rates even in the presence of high user demand. However, the best way of integrating interference-adaptive power control with channel assignment is currently unknown. While a firm analytical base remains to be developed, the evidence shows great potential for simple, distributed DCA to enhance capacity. For some operators, the promise of a self-organizing,"plug-and-play" system is more important than capacity gains.

Important issues of DCA realization remain. Since DCA typically assigns channels as close to the acceptable-SIR level as possible, re-assignment may be necessary as other users come and go and as the desired signal itself changes. Extreme cases such as mobile users turning street corners in microcells may require greater SIR margins, thus decreasing capacity [14]. First- and second-generation cellular standards lack the measurement and communication features required for an efficient DCA. Delay must be controlled: searching perhaps hundreds of channels may take seconds or tens of seconds, which is unacceptable if it occurs in "real time" while the user is awaiting connection. This consideration places obvious constraints on SIR measurement and channel-search techniques. Also, TDMA-based DCA requires base-to-base synchrony for full capacity gain [10]. Finally, interference-adaptive DCA seems conceptually matched only to a circuit-switched structure; the measurement delays and other overhead, which might be a small fraction of the typical circuit holding time, loom very large when assessed for each data packet or talk spurt in a packet-switched system. We are not aware of proposals combining true DCA with packet-switched operation.

Code Division Multiple Access CDMA Systems

Code division multiple access (CDMA) has many virtues, as discussed in [5] and other articles in this issue. Of paramount importance is the fact that CDMA uses single-cell clusters. Although there is interference between cells, CDMA systems are able to cope with it. Further, sectorization does provide capacity gains, even in a one-cell cluster, and the gain is nearly proportional to the order of the sectorization. Siting BSs in the most complex of environments is straightforward compared to fixed channel assignment (FCA) TDMA or FDMA. Basically the BSs in CDMA are sited to provide contiguous coverage with cell overlaps sufficient to provide handover. No frequency planning is required in CDMA networks due to the one-cell clusters which all use the same carrier frequency. However, CDMA systems will likely respond to under-engineering, extraordinary propagation, and external interference in novel and unpredictable ways. Network planners and managers must learn different methods to predict, detect, and correct the consequent performance problems.

Soft handover (SHO) is used in CDMA. This is necessary to avoid near-far problems at the cell-edge due to cell-membership ambiguity, and also provides multiple base station diversity because the MS is receiving transmissions from both the original BS and from the future one. Typically, the MS has a number of baseband receivers (three or four), which lock onto the strongest paths from both BSs, and the outputs from these receivers are combined. This arrangement also allows both BSs to control the MSs transmit power. SHO requires the use of channels in both BSs, and in CDMA it is desirable to design the BSs to have sufficient number of channels to handle both SHO for mobiles between cells, and softer handover (SSHO) between sectors of the same cell. When HO to an oversailing cell uses a different radio frequency carrier, an HHO is performed.

When multicarriers are used in CDMA, i.e., we have a CDMA/FDMA situation, each BS uses some or all of the carriers. If oversailing macrocells are deployed, they must use different carriers from those used by the microcells in order to comply with the onerous power control requirements, which are significantly more stringent than those for TDMA or FDMA systems.

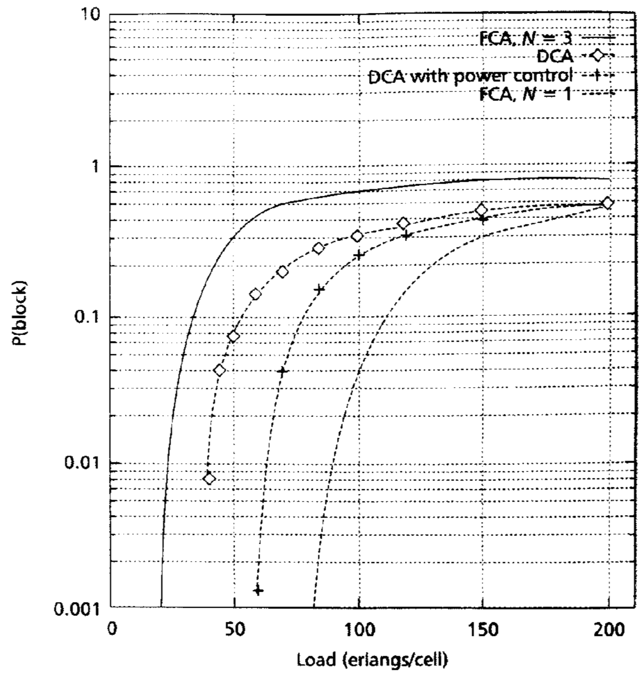
Statistical Multiplexing

The bit rate to efficiently encode speech varies in time, as the speech activity changes from speech where the autocorrelation is low to intervals of silence. To achieve efficient utilization of channel resources, speech users may be statistically multiplexed together. Unfortunately, multiplexing creates another problem, that of insufficient resources to accommodate all service requests in moments of peak demand. For packetized speech transmissions, excessive delay must be avoided and as a result packets that arrive after an acceptable delay period are dropped. To maintain good recovered speech quality the dropping rate must be low, and post-processing of the recovered speech using waveform substitution techniques may be deployed [16]. In general, the greater the number of channels to be multiplexed, the higher the multiplexing gain, i.e., the ratio of the number of speech users supported to the total number of available channels.

Statistical multiplexing of speech users can only be achieved if there is an effective and responsive signaling mechanism that will allocate channel resources on demand. In a packet transmission system, the control information constitutes an important part of the protocol. A well designed multiple access technique tries to keep this overhead low, while at the same time ensuring that the system remains stable if this control information is lost or corrupted during transmission. The control information helps to provide not only all the functions of call set-up, call maintenance, and call clear-down, but also functions related to dynamic packet slot allocation, reservation, and deallocation in a statistical multiplexing system. With the advent of microcells, the speed and reliability of this control information is even more crucial. While it is convenient to encapsulate the control information with the speech data, as in most packet switched networks, this tends to consume more bandwidth. Given the scarcity of frequency spectrum in wireless networks, a system with independent, but integrated, signaling and speech channels is worthy of consideration. We emphasize that the amount of control information, its frequency, and degree of error protection have an impact on the final design of the multiple access protocol.

Shared Time-Division Duplexing

Time-division duplexing (TDD) is an arrangement where the transmission and reception of traffic occur via the same carrier, but at different times. Better utilization of channel resources is obtained if the speech users are statistically multiplexed through the use of speech activity detection (SAD). In a two-way conversation, it is usual for only one of the parties to be active at any instant. Consequently high statistical multiplexing gains may be achieved even with a low number of users, if the teletraffic from both conversation paths is multiplexed into a common channel. The resulting shared time-division duplexing (STDD) scheme has a control channel with an equal number of uplink and downlink slots, where all functions pertaining to call management, including handovers and terminations, are handled. These control slots are allocated to users in a structured manner [16]. Let us suppose there are C uplink and C downlink control slots, and N shared speech slots as shown in Fig. 6, and that the maximum number of pairs of users is U (U being a multiple of C and $2U > N$). In general, $C < U$, and hence only C pairs of users can communicate their control information to and from the base station in one frame



■ **Figure 5.** *Blocking performance of FCA, DCA, and DCA/power control with 108 channels.*

Uplink control Channel (C slots)	Downlink control Channel (C slots)	Shared speech channel (N slots)

■ **Figure 6.** *STDD frame structure.*

period. This means that it takes a total of $K = U/C$ frame periods for all users to be serviced in this way, i.e., K is the duty cycle to service all users' signaling requirements. This access mechanism ensures that all users are guaranteed service within K frame periods. At the same time, since acknowledgements are communicated within the same frame period, a user with an acknowledged reservation can immediately send his speech packet within the same frame. For example, if the frame period is 2 ms, $U = 40$, and $C = 5$, then the duty cycle is 8 with a cycle period of 16 ms. To minimize the impact of base-to-base co-channel interference synchronized frame transmission is necessary. In addition, two mechanisms may be employed to limit interference. First, uplink and downlink slots are allocated from opposite ends of the shared channel. Second, dynamic slot allocation may be employed to further contain the problem.

The slots in the speech channel are shared by both the uplink and downlink transmissions. When there are only a few users, there are usually more than enough slots to meet all users needs. However, as the number of users increase, the number of speech slots may be insufficient to support a momentary peak demand. When this happens, speech packets that exceed a predetermined age limit are dropped. Often not all the speech slots are consumed and this spare capacity may be used as

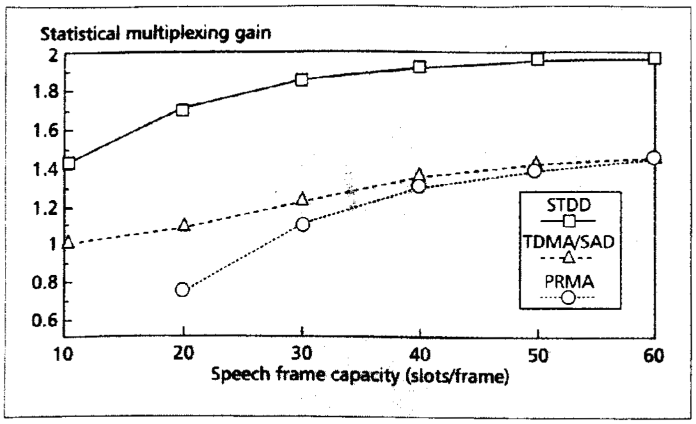


Figure 7. *Speech statistical multiplexing performance for different multiple access schemes: 10-ms frame duration.*

a random access channel for new calls to be set up. The comparative performance of STDD, TDMA with SAD, and packet reservation multiple access (PRMA) is shown in Fig. 7. TDMA with SAD is essentially a pair of TDMA channels for the up and down links with dynamic allocation of the TDMA slots only during talkspurt intervals. On the other hand, PRMA is a random access packet switched protocol with provision for making reservations [17]. Over a range of frame sizes, STDD achieves the highest statistical multiplexing gain which translates to more efficient utilization of channel resources.

A Saucer of Cream

Currently cellular systems use FCA, while cordless telecommunication (CT) networks in offices have a primitive form of DCA. Because dense urban teletraffic will eventually be carried by microcellular networks whose microcells have complex three-dimensional volumes, TDMA with DCA or CDMA systems will be used to avoid complex frequency planning requirements. Increasing spectral efficiency may also require statistical multiplexing which embraces both PRMA and STDD. However, we emphasize that the greatest single factor in enhancing spectral efficiency of a network is not complex multiple access techniques, efficient speech and channel coding, modulation, powerful protocols, etc., but the mass deployment of microcells. By this simple technique we can repeatedly and efficiently reuse the precious spectrum. We await the arrival of low cost microcellular BSs and their interconnecting infrastructure like a cat awaiting a saucer of cream!

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