Teletraffic Performance of GSM900/DCS1800 in Street Microcells

Radio planners often refer to the buildings in cities as "urban clutter," a nuisance they must accommodate. A more appropriate attitude for personal communication systems is to utilize the electromagnetic shielding offered by buildings to form microcells.

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Most cellular systems currently use macrocells, which are formed in cities by siting the base station (BS) antennas on the top of tall buildings. Radio planners often refer to the buildings in cities as "urban clutter," a nuisance that they must accommodate. A more appropriate attitude for personal communication systems (PCS) is to utilize the electromagnetic shielding offered by buildings to form microcells, i.e., small cells whose shapes are determined by the cross-sectional area of the buildings and the topology of the roads [1-4]. In this article we will ignore building heights, as we will site the microcellular BS antenna below the urban skyline. Microcells, being small cells, are used to dramatically increase the capacity of a PCS network. Interconnections of microcellular BSs may be accomplished by means of an optical local area network (LAN).

We will not focus here on microcellular BS design, interconnection issues, or handover speeds. Our aim is to study the teletraffic issues of the Global System of Mobile Communications at 900 MHz (GSM900) [5-7], and its sister, the Digital Communication System at 1800 MHz (DCS1800) [8, 9]. Our teletraffic simulations will have the essential elements of GSM900 and DCS1800, but they will not be exact simulations of these two systems. Our approach is to site microcellular BSs, using our microcellular prediction tool MIDAS,[1] into a fictitious city and into parts of two real cities [3]. The radio coverage plots will then be imported into a teletraffic simulator called TELSIM.[1] The simulator will be loaded with the basic GSM900 and DCS1800 parameters to give an indication of the teletraffic performance of these systems in our three environments.

Street Microcellular Environments

Three street microcellular environments will be considered. The first is a rectilinear pattern of streets, which does occur in parts of some cities; the next is an example of a part of a large U.S. city; the third is the center of a provincial European city.

Rectilinear Street Microcells

When analyzing the performance of macrocells, it is customary to use tessellated hexagonal macrocells. These cells cannot be physically realizable, but they have the virtue that different types of mobile radio networks can be compared for the same cellular structure. The equivalent cellular structure for street microcells is a grid of North-South and East-West roads of identical dimensions and spacing. Between the roads are buildings with the dimension of a city block [4]. In our rectilinear street model we arbitrarily assign the distances between the centers of adjacent roads as 100 meters. The width of the roads is 20 meters. The buildings are 72 meters square, but when the sidewalks around the buildings are included, the dimensions increase to 80 meters square. We will not concern ourselves with the heights of the buildings on the proviso that the antenna heights of the microcellular BSs are well below the urban skyline, a condition that is easy to satisfy in city centers. Diffraction of electromagnetic waves over the roofs of the buildings is therefore negligible.

We commence by considering a GSM-like network. The microcellular BSs are located at some road junctions. For propagation frequencies close to 900 MHz, a microcellular BS located at a road junction forms a microcell that is essentially a cross. If the path loss at the microcellular boundaries is to be, for example, less than 80 dB, the arms of the cross will extend beyond two roads, with the dimensions from the BS to the boundaries being approximately 240 m. The coverage will marginally extend into some of the other roads. Notice that if the road spacing had been closer (or the propagation frequency lower) the microcell would have extended over more blocks, whereas if the road spacing was larger (or the propagation frequency higher) each microcell would have covered only part of a city block. In selecting the dimensions of our rectilinear street model, we observed existing street plans and concluded that the dimensions presented above do occur, but their exact values are less important than our main objectives, which relate to comparative teletraffic performances in a given road topology.

TDMA systems use tessellated clusters of microcells. We arrange for each cluster to utilize the

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[1] *MIDAS and TELSIM are proprietary products from Multiple Access Communications Ltd.*

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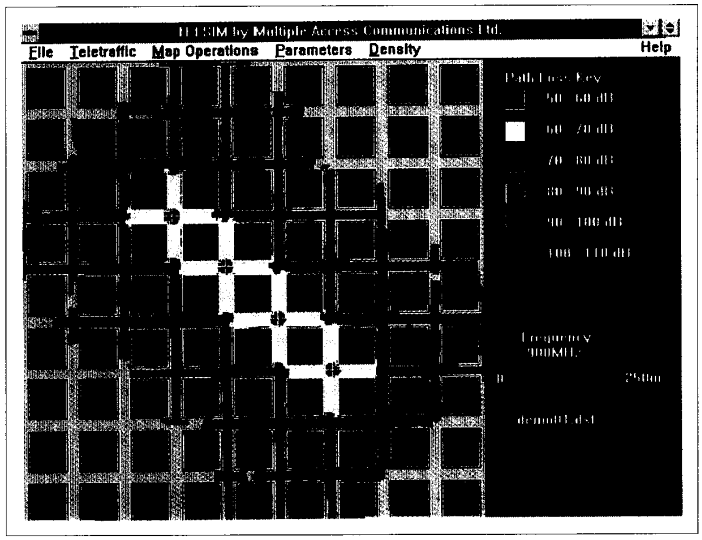
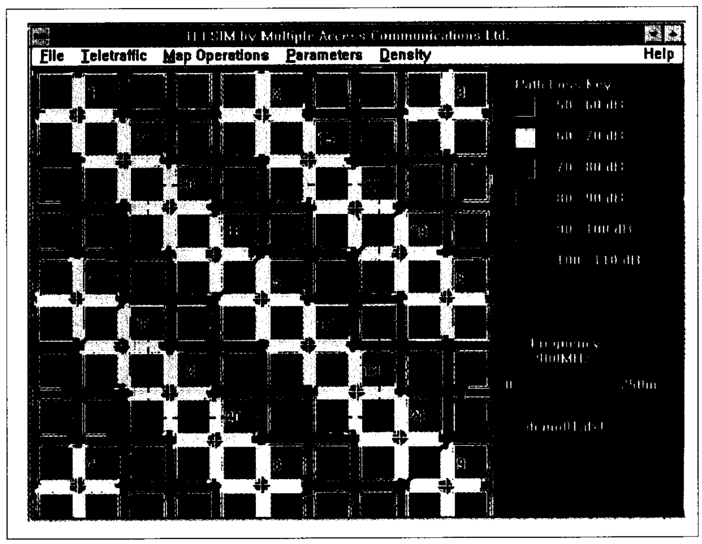
entire frequency band assigned to the microcellular network. Figure 1 shows the coverage of a four-microcell cluster, where the position of each BS is shown by a cross. The coverage of this cluster is indicated by the red-blue interface. The propagation frequencies are in the 900 MHz band. Tessellated clusters are shown in Fig. 2. The numbers identifying the base stations have no significance other than the order in which their coverage was predicted. The BSs numbered 16, 1, 5, 9, and 19 all have the same channels, and therefore they interfere with each other to some extent. This interference is called cochannel interference. Similarly, frequency sets are shared by BSs numbered 12, 14, 17, 2, and 6; BSs 7, 20, 10, 13, 15, and 3; and by BSs 4, 8, 18, 21 and 11. At this point we are not concerned with how many carriers there are per frequency set. The dark gray diagonal lines show how the microcells are clustered. For example, BSs 5, 17, 13, and 21 form one microcellular cluster. The microcells have been sited such that the signal-to-interference ratio (SIR) over most of the microcell exceeds 20 dB, but that on two East-West roads the SIR is between 10 and 15 dB. By using more microcells per cluster, the SIR could be arranged to always exceed 20 dB. However, GSM900 is alleged to operate for SIR ratios down to 9 dB, although an SIR of 12 dB is a safer design figure to use. We observe that the smaller the cluster size, the greater is the spectral efficiency measured in Erlangs/MHz/km^2.

DCS1800 operating with the same rectilinear street dimensions produces much smaller microcells. For a BS located at a cross-road the coverage out to 80 dB only goes as far as the center of the next four crossroads, i.e., the microcell is a cross whose four perpendicular arms are essentially a city block in length. Thus, for DCS1800 the BSs are separated on East-West or North-South streets by two blocks. Figure 3 shows tessellated clusters where each cluster has four microcells. Again, the microcell boundaries have been set where the path loss is less than 80 dB. We observe that for the same coverage criterion, DCS1800 requires twice the number of BSs compared to GSM900. The SIR values in the microcell exceed 20 dB for 90 percent of the area, and the lowest SIR is 10 dB.



■ **Figure 1.** *Coverage of a cluster of four microcells at 900 MHz.*



■ **Figure 2.** *Tessellated clusters of microcells with four microcells per cluster at 900 MHz.*

Dallas, USA

Using maps made from aerial photographs,[2] where the exact cross-sectional areas of the buildings and some side streets have been omitted, we made coverage predictions at 1800 MHz for DCS1800. Zooming in to an arbitrary area of Dallas, in Fig. 4 we show microcellular BSs numbered 1 and 10 having the same frequency set, as do BSs numbered 2 and 12; 3 and 19; 4, 15, and 17; 5 and 9; 6, 11, and 18; 7, 13, and 14; and 8 and 16. Therefore, the reuse factor or cluster size was 8.

Southampton, UK

Whereas Dallas is a modern city with large freeways and skyscrapers located on a flat Texan plain, Southampton is a seaport town whose origins date back to the Roman conquest in A.D. 43, when the Second Legion under Vespasian set up a supply base there. The streets of Southampton are far from regular, there are no skyscrapers, and part of the surviving medieval walls reside within our microcellular plan. Precise maps with a scale of 1 to 1250 are supplied by the Ordnance Survey in the United Kingdom, giving details of the cross-section of the city down to one meter. Figure 5 shows a microcellular network having 17 GSM900 microcells arranged with six microcells per cluster. With this type of city, four microcells per cluster cannot be achieved with our microcellular coverage for path loss up to 80 dB and for the SIR ratios exceeding 9 dB, as required for GSM900. In Fig. 5 the microcellular BSs numbered 1, 16, and 17 have the same frequency set, as do BSs numbered 2, 5, and 15; 3, 4, and 13; 6 and 12; 7, 8, and 10; and 11, 14, and 18, corresponding to a reuse factor of 6.

Figure 6 shows the positions of microcellular base stations for a DCS1800 PCS that spans an area approximately the same as the PCS for GSM900 shown in Fig. 5. Whereas GSM900 requires 17 microcells, DCS1800 has 24 microcells. This is in contrast to the PCS based on rectilinear roads, where DCS1800 requires twice the number of BSs.

2 By CNet of Dallas.

It is the complex street topology of Southampton that results in the number of BSs required in DCS1800 and GSM900 being relatively similar if contiguous radio coverage is to be assured. Eight frequency sets are required with microcellular BSs: 1, 7, 16, and 9; 2 and 15; 3, 4, 10, and 17; 12, 13, and 24; 5 and 14; 6 and 11; 8, 18, 21, and 23; and 9, 20, and 22 in sets 1 to 8.

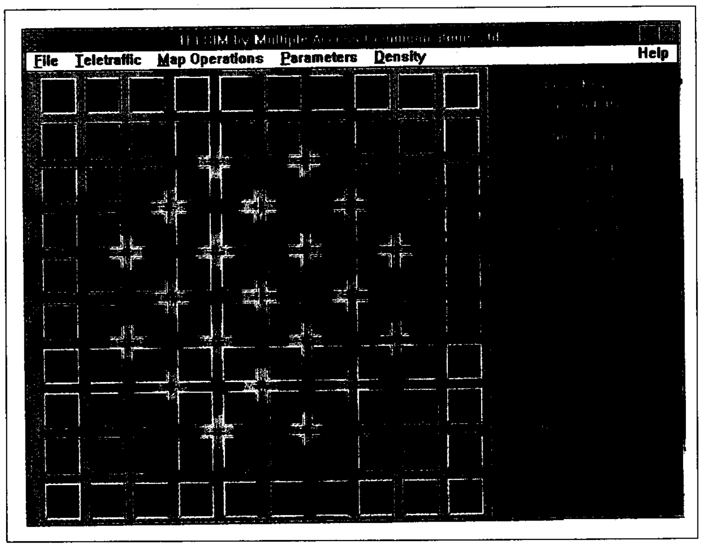
Teletraffic Simulator

The teletraffic simulator imports the coverage predictions and determines the probability of new calls being blocked and the probability of existing calls being forced to terminate for a variety of scenarios. When the simulation is running, mobiles engaged in calls and depicted by a small cross are seen traveling along the streets with a line connecting them to the BS with which they are communicating. Handovers are seen on a computer screen as the line switches from an old BS to a new BS. Figure 7 shows a snapshot of the screen displaying mobiles traveling in the streets of Southampton.

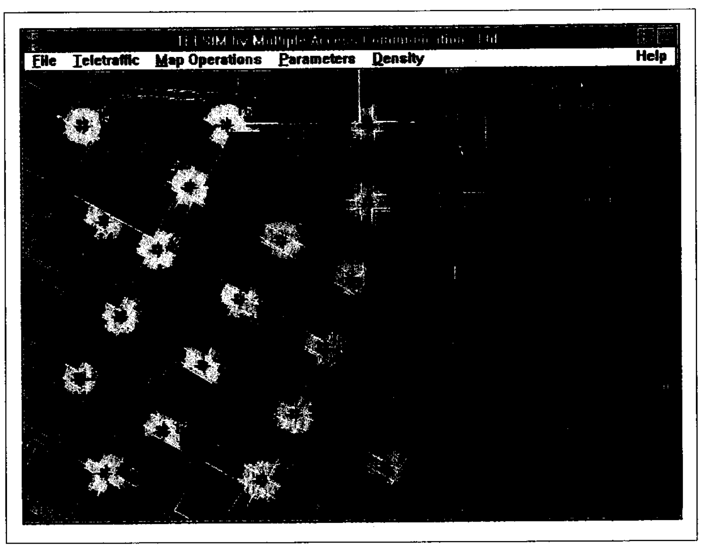
The simulator allows us to partition the map of the city into squares and to assign different density of users to each square prior to commencing the simulation. The users move with uniformly distributed direction and Rayleigh distributed speed, with the constraint that they are confined to the roads. Each user is independent, offering the same average teletraffic. The call durations have a negative exponential distribution, and when voice activity is used to provide discontinuous transmissions (DTX), the Brady voice model is applied [10]. With DTX no transmissions are made in periods of speech silences. (GSM900/DCS1800 does maintain information flow during silences, but at a low bit rate.)

The simulation supports many features not required for Phase I GSM900/DCS1800. (It does support FDMA, CDMA, dynamic channel allocation (DCA), multiple slot calls, adaptive multilevel modulation, and so forth, enabling many systems from analog cellular to IS-95 and DECT to be approximated and compared.) We will use fixed channel allocation (FCA), and power control will be applied to both the up- (forward) and down- (reverse) links. Intracellular and intercellular handoffs (HOs) will be allowed. The SIR and signal-to-noise ratio (SNR) thresholds can be set for HOs and timers introduced, so that HOs are implemented after a set time following the thresholds being exceeded. We can arrange to reserve a set of channels exclusively for HOs. An overlaying macrocell may be deployed. This is fictitious, as it is assumed that the macrocellular coverage is total. The macrocellular BS can be used to provide coverage in radio dead-spots in the microcellular clusters, and/or to act as a support for mobiles that cannot find a channel following an HO request.

Upon call initiation the mobile requests a channel from the closest microcell. If no suitable channel is found, the call is blocked, unless there is a macrocell present. When a macrocell is present, it provides support to overloaded microcells upon call initiation. Only if the macrocell is congested will the call be blocked. Note that new calls blocked by the most appropriate microcell are not offered to alternative microcells, but to the macrocell.



■ **Figure 3.** *Tesellated clusters of microcells with four microcells per cluster at 1800 MHz.*



■ **Figure 4.** *Microcells in arbitrary positions in a part of Dallas —frequency 1800 MHz.*

Teletraffic Parameters

We arranged for the offered traffic per user to be 12.5 millierlangs (mEr) and the mean call duration to be 120 s. Initially, the number of users were uniformly distributed, and any users who were making a call when they reached the boundary of the map were bounced back inside the map and were able to continue with their calls. We assigned one carrier per microcellular BS and, because this carrier was required to carry the broadcast control channel (BCCH), neither power control, frequency hopping, nor DTX were allowed. This carrier supported a TDMA frame with eight slots, with one slot used for control (including the BCCH) and the others for traffic. Only the seven traffic channels were modeled in the simulation. The BS and mobile station (MS) antennas were omnidirectional.

The peak transmit powers of the BSs and MSs were both set to 10 mW or 10 dBm. The noise floor of the MS was –100 dBm. To initiate a call, both the SNR and the SIR had to exceed 12 dB at both the MS and the BS. When either the SNR or the SIR was less than 9 dB, the dropping counter was incremented and continued to be so, unless these conditions improved when the counter was reset. If the counter was not reset and reached 5 s, the call was dropped.

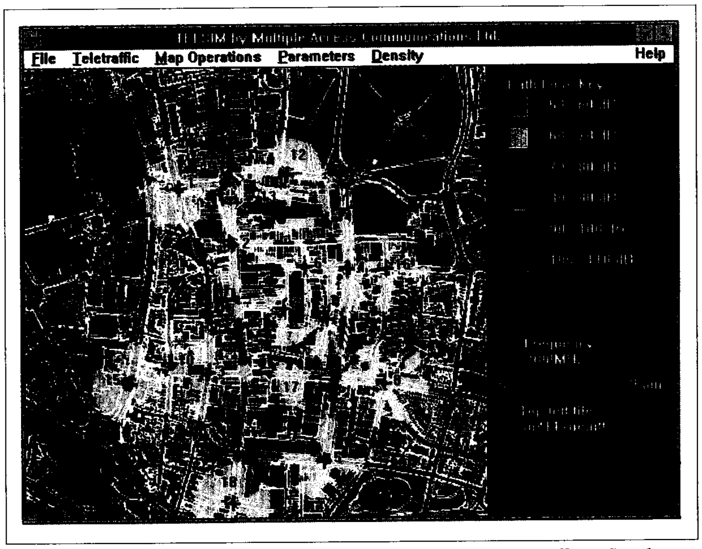
The MS checked every simulation iteration cycle, set here to 1 s, to confirm that it was being served by the BS associated with the lowest path loss. If the situation changed, and another BS offered a path loss at least 3 dB lower, it requested a handoff (HO) and set a timer in motion. At the end of the HO timer period an intercellular HO ensued. In our simulation the timer period was set to zero. If there was not a BS with a path loss at least 3 dB better than that offered by the current BS, it remained with this BS. When the SIR was below 12 dB, the HO timer was incremented and the MS changed its slot.

Teletraffic Performance

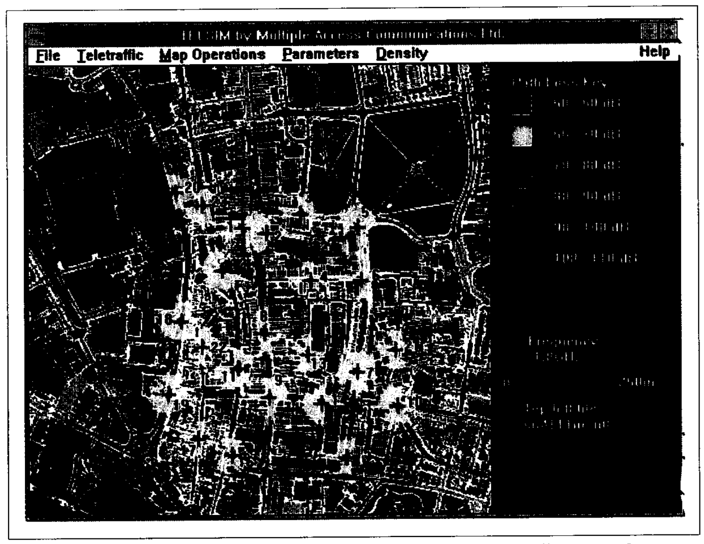
Rectilinear Street Microcellular PCS

There are gaps in the required 80 dB coverage at the edges of the rectilinear pattern of microcells shown in Fig. 2. As a consequence, we gathered teletraffic statistics for the square, shown in dashed lines, with five roads centered around microcellular BS (numbered 5 and situated in the middle of the figure). The variation of the blocking probability of new calls (P_b) and the dropping probability of existing calls (P_d) was investigated for mobiles traveling at 1, 5, and 10 m/s. The propagation frequency was 900 MHz, i.e., the results apply for GSM900. The blocking and dropping probabilities behaved similarly for the two higher speeds, 5 and 10 m/s, but were somewhat different in the low-speed case, 1 m/s. In the high-speed case the blocking probability, P_b, varied from below 0.1 percent for a total offered traffic (A) of 12.5 Er (1000 users with 12.5 mEr/user) to 9.5 percent for A = 37.5 Er. The dropping probability, P_d, varied less, from 0.4 percent to 1.5 percent, as A increased from 12.5 Er to 37.5 Er. In the low-speed case, i.e., average speed V = 1 m/s, we found that blocking was slightly lower — below 0.1 percent for 12.5 Er and rising to 8 percent for A = 37.5 Er. The corresponding variation of P_d was 2.1 to 3.7 percent. This increased rate of call dropping permitted more new calls to be accommodated, thus accounting for the difference in blocking between the low- and high-speed cases. As microcell 5 carried the largest traffic because its coverage extended over most of the square, its performance was the most influential on the results given above. We observed that the P_d of this central microcellular BS was essentially the same for all values of V, and for an A of 25 and 37.5 Er it was approximately 7 and 21 percent, respectively.

For DCS1800, the square of the same dimensions of five-by-five roads had significantly more BSs. In particular, there were five BSs whose coverage area did not butt against the square boundary.



■ **Figure 5.** *Locations of base stations in 17 GSM900 microcells in Southampton. © Crown copyright.*

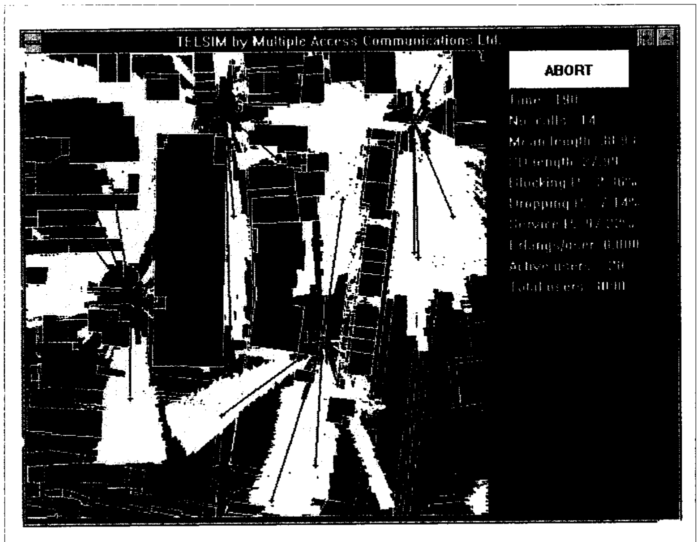


■ **Figure 6.** *Locations of base stations 24 DCS1800 microcells in Southampton. © Crown copyright.*

The teletraffic carried was more evenly distributed among the BSs, there were more channels available, and as a consequence P_b and P_d were considerably decreased compared to those for GSM900. For example, for a 37.5 Er load, P_b and P_d were acceptable, as they never exceeded 1.7 percent and 0.9 percent, respectively, for values of V from 1 to 10 m/s.

Southampton Microcellular PCS

The microcells for the GSM900 PCS network are shown in Fig. 5. We arranged for the MSs to roam anywhere over the 1 km-by-1 km area, and those that arrived at the edge of this area were turned back with a reflected velocity vector. With no overlaying macrocell, MSs that ventured beyond the microcellular PCS while making a call had their calls terminated. For MSs having an average speed of V= 1 m/s and 10 m/s, P_d was approximately constant at 12 percent and 17 percent, respective-



■ **Figure 7.** *Snapshot of mobiles travelling in Southampton. © Crown copyright.*

ly, irrespective of the number of users. The P_b increased exponentially from 0.03 percent for an A of 12.5 Er to 1.8 percent for 37.5 Er of traffic when the MS average speed was 1 m/s. For a V of 10 m/s, P_b remained negligible, reaching 0.1 percent when A reached 37.5 Er.

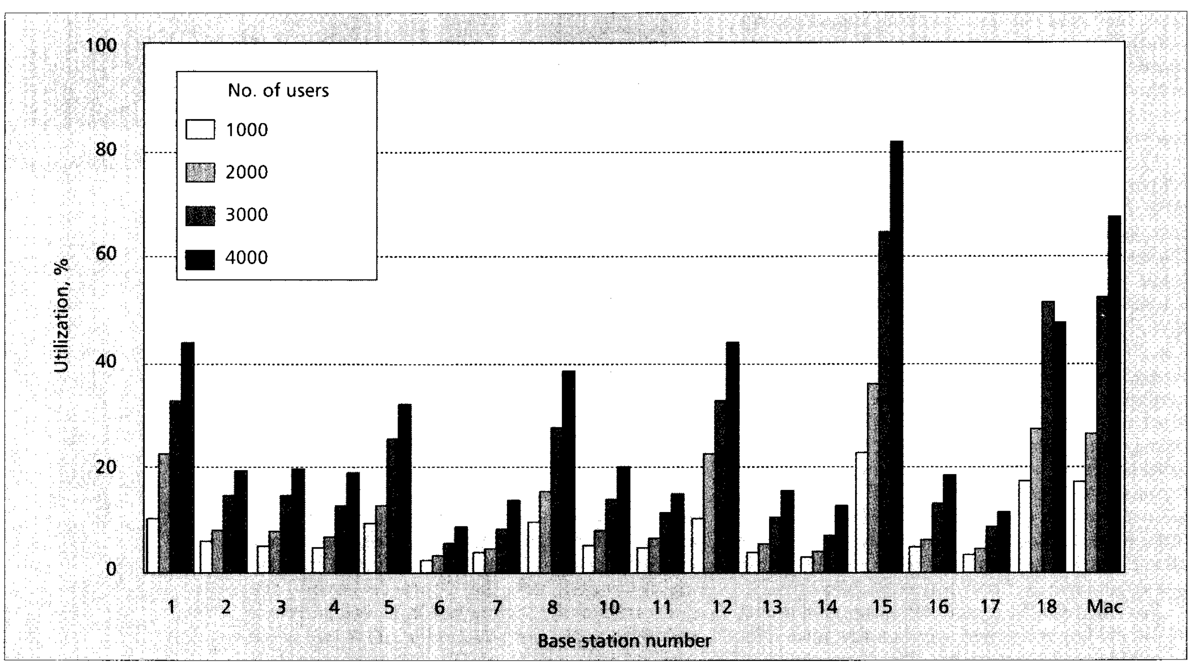
An overlaying macrocell was introduced. None of its channels were exclusively assigned for HO purposes. An MS was required to initially attempt HOs with the microcellular BSs, but if this could not be achieved due to unacceptable SIR and/or SNR values, or because of a lack of available microcellular channels, then the MS was allowed to attempt an HO to the macrocellular BS. MSs were forced to attempt registration on a microcellular BS, but when this could not be done, it was allowed to register onto the macrocellular BS. Because a significant part of the map shown in Fig. 5 does not include the PCS network, the effect of the presence of the macrocell with its 22 channels was to dramatically decrease P_b to zero for A less than 30 Er, increasing to 0.08 percent when A increased to 37.5 Er (equivalent to 3000 users) and 1.2 percent when A is further increased to 50 Er. Figure 8 shows a bar chart of channel utilization for each of the BSs, and for the overlaying macrocellular BS. Microcell sites numbered 12, 15, and 18 are on the periphery of the PCS network and therefore carried extra traffic because of mobiles leaving this network that could not be handled by other microcellular BSs.

Relatively small microcells that were not near the edges of the PCS network, such as microcells 6 and 7, had a low channel utilization. The main role of this type of BS was to provide coverage rather than capacity. For uniform channel utilization the design procedure would be to allocate more channels to BSs on the periphery of the microcellular PCS network, or to extend the PCS to areas of lower traffic density.

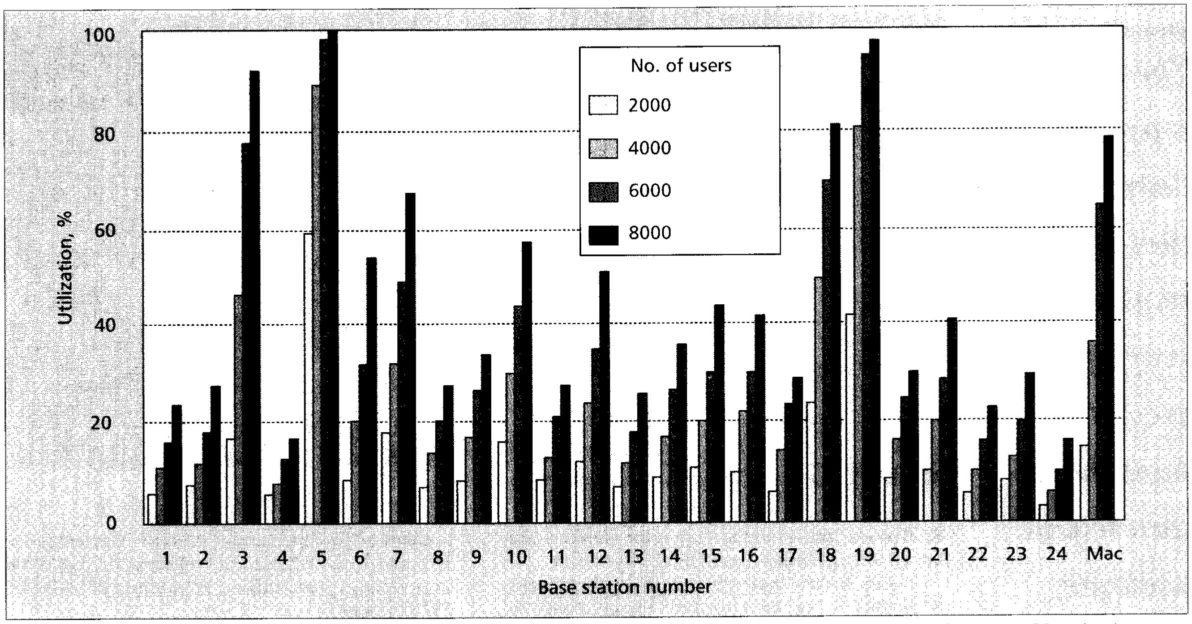
The bar chart of channel utilization for the DCS1800 network shown in Fig. 6 is displayed in Fig. 9. The peripheral microcells 3, 5, 18, and 19 were heavily utilized, while the utilization of the inner microcells was relatively low. We do not display the bar chart for channel utilization in the absence of the macrocell, but the effect of deploying the macrocell was to increase the channel utilization.

Dallas DCS1800 Microcellular PCS

Without a macrocell, P_b was less than 0.4 percent above our range of A from 12.5 to 37.5 Er. The P_d for a V of 10 m/s was approximately constant at 20 percent. When the macrocell was added with



■ **Figure 8.** *Channel utilization for each BS and the overlying macrocellular BS for GSM900 PCS in Southampton,* V = *1 m/s.*

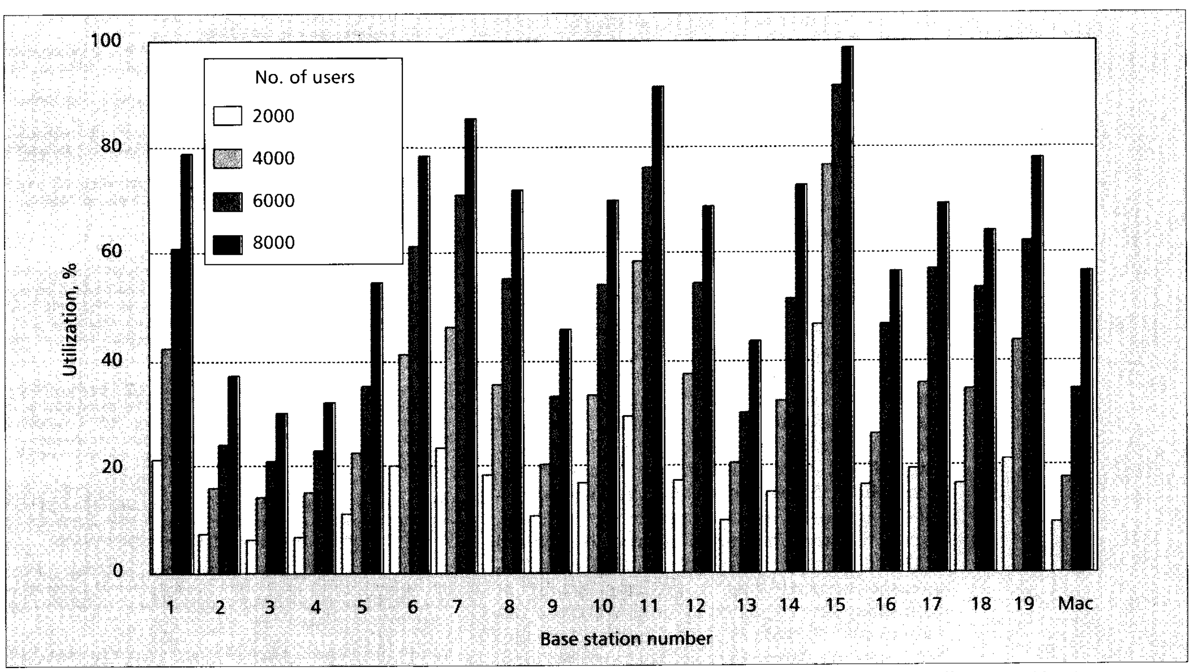


■ **Figure 9.** *Channel utilization for each BS and the overlaying macrocellular BS for DCS1800 PCS in Southampton,* V = *1 m/s.*

its 22 channels, no new calls were blocked for a V of 10 m/s, while P_d decreased to less than 0.4 percent over the offered traffic range. The traffic utilization for Dallas is shown in Fig. 10.

Conclusions

We have examined three types of radically different street microcellular environments. The rectilinear one is often used as a bench marker and also because it does exist in some cities. Old cities, as exemplified by Southampton, have street and building topologies that are very different from the rectilinear environment. The spectral efficiency in terms of Er/MHz/km^2 for a new call blocking probability of 2 percent is significantly higher in rectilinear topologies compared to irregular ones. In addition, DCS1800 PCS operating in rectilinear streets requires twice the number of microcellular BSs compared to GSM900 for contiguous coverage. However, in Southampton the ratio was found to be much less, approximately 24/17. Also, the reuse factor in Southampton was not 4 but 6 for GSM900. For DCS1800, the reuse factor was



■ **Figure 10.** *Channel utilization for each BS and the overlaying macrocellular BS for DCS1800 PCS in Dallas,* V = *10 m/s.*

The design of a personal communication system requires propagation prediction tools that in turn require accurate digital maps.

Map	System	Speed (m/s)	Area (Km2)	Bandwidth (MHz) Macrocell	Bandwidth (MHz) Microcell	Spectral Efficiency (Er/MHz/Km²) Macrocell Only	Microcells Only	Complete System
Rectilinear	GSM900	1	0.25	7.2	0.8	8.27	123	not simulated
		5					117	
		10					117	
	DCS1800	1	0.25	7.2	0.8	8.27	219	not simulated
		5					194	
		10					200	
Southampton	GSM900	1	0.81	7.2	1.2	2.55	38.6	7.9
	DCS1800	1	0.65	7.2	1.6	3.15	29.2	15.3
Dallas	DCS1800	10	0.84	7.2	1.6	2.44	37.2	15.2

■ **Table 1.** *Spectral efficiency of the microcellular systems.*

8. Of course, these numbers apply for a limited number of microcellular clusters in a city center.

Dallas is a city that at first sight might appear to be rectilinear, but closer inspection reveals roads that are offset and of differing widths and lengths, as shown in Fig. 5. As DCS1800 is of interest in the United States, we have not investigated GSM900 in this city. The reuse factor was found to be 8, consistent with the PCS network in Southampton.

We assigned only one carrier with its eight TDMA slots to each microcellular BS, as we consider this to be a likely scenario. We also introduced an overlaying macrocell with three carriers corresponding to 24 channels, of which 22 were used for traffic and the other two for control [5]. The macrocell is particularly useful for mobiles who wander outside the microcellular clusters and for mobiles in the PCS network who find themselves in difficulties. As people often walk in Southampton and drive in Dallas, our traffic utilization graphs are shown for average mobile speeds of 1 m/s and 10 m/s, respectively. Note that the mobile speeds are Rayleigh distributed. The general conclusion is that for our scenarios some BSs near the PCS periphery have the highest utilization as they have to provide channels to mobiles coming and leaving the PCS.

Table 1 shows the spectral efficiency in Er/MHz/km^2 of our scenarios. We assumed that one macrocellular sector covered the entire simulation area. It had three transceivers and was part of a three-sector, four-cell reuse pattern. Therefore, 36 GSM carriers or 7.2 MHz was required for macrocellular coverage. Note that microcells without macrocell support have the greatest spectral efficiency, although if contiguous coverage is required, an overlaying macrocell is essential. The microcellular layer dramatically increased the spectral efficiency of the macrocellular PCS. DCS1800 systems had a greater spectral efficiency than GSM900 because of the smaller cells resulting from a maximum path loss of 80 dB; hence, the larger number of microcells required in the rectilinear configuration. However, this increase was partly offset by the larger number of frequency sets required at 1800 MHz as compared with 900 MHz in Dallas (not shown) and Southampton. When the macrocell was included, we found that the DCS1800 systems in Southampton and Dallas had similar spectral efficiencies of 15.3 and 15.2 Er/MHz/km^2, whereas the GSM900 in Southampton had an efficiency of only 7.9 Er/MHz/km^2.

The design of a PCS requires propagation prediction tools that in turn require accurate digital maps. Armed with PCS clusters providing contiguous coverage, a simulator is necessary, since many alternative scenarios can be quickly investigated. We present some of these scenarios to illustrate the methodology involved, not optimized solutions.

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