REPORT 740-2 *

GENERAL ASPECTS OF CELLULAR SYSTEMS

(Question 37/8)

(1978–1982–1986)

1. Introduction

Systems are in use for the land mobile service which utilize the frequency spectrum much more efficiently than conventional systems [Schulte and Cornell, 1960; Frenkiel, 1970; Staras and Schiff, 1970]. The technique which such systems have in common is the division of the desired service area into a number of sub-areas (cells), with one or more base stations providing radio coverage to each cell.

Appropriate frequency planning permits frequencies to be used several times in a coverage area. The cellular technique can also be combined with the trunking concept (see Report 741), thereby improving spectrum utilization efficiency.

2. General system characteristics

When a mobile unit either originates or is prepared to receive a call, the cell which can best serve the unit is selected (e.g. through an algorithm resident in the logic of the mobile unit) and it communicates through a base station covering that cell. With the proper spacing of co-channel cells, each frequency may be used simultaneously in several cells in the service area, thereby multiplying the capacity obtainable in conventional systems.

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* This Report should be brought to the attention of Study Group 1.

The general features of a cellular system are:

- accommodation of more than one base station in a service area and thus the expansion of the service area of the system beyond the coverage that a single site provides;
- "hand-off" or transfer of the responsibility for radio coverage of a mobile or hand-held unit from one site to another, i.e. from one radio frequency to another;
- re-use of the same RF assignment simultaneously by more than one base station and for more than one message; this is the cornerstone of the *spectral utilization efficiency* of cellular systems;
- growth; that is, the system must be able to start with a few large cells and gradually grow until many small cells are created at the points of highest traffic density.

These features are essential for a complete cellular system. However, specific equipment arrangements may create systems that are "cellular compatible" (that is, inter-operable with true cellular systems) even though they do not possess all of these attributes. For reasons of economy, the base station equipment used in a small city may not permit the simultaneous existence of two cell sizes, while more sophisticated equipment used in a large city where maximum capacity is required will be fully compliant; the same mobile units will work in either area.

3. Channel re-use considerations

3.1 *General*

The rejection of co-channel interference depends solely on the carrier-to-interference (C/I) ratio and not on absolute amplitude. Since median C and median I are inversely proportional to a power of the distance from the source, the required co-channel cell spacing (called D) can be specified as some multiple of the cell radius (called R), depending on the median C/I desired.

To a good first approximation:

$$C = k/R^n, \quad I = k/D^n$$

thus:

$$C/I = \left(\frac{D}{R}\right)^n \quad \text{or} \quad D = R\left(\frac{C}{I}\right)^{1/n}$$

Reducing D and R in proportion would allow each frequency to be re-used simultaneously in more cells in the service area. However, it could also increase the mutual interference between co-channel stations beyond usable limits, unless other techniques, such as diversity [Lundquist and Peritsky, 1971] and power control [US Advisory Committee, 1967] are used. The re-use distance must be large enough to give an acceptably low probability of co-channel interference as a result of the propagation conditions [Okumura, 1968], of multipath fading (which has a Rayleigh density function) and log-normal shadowing (slow-fading) experienced in the land mobile service.

The re-use ratio D/R is related to number of channel sets n by:

$$D/R = \sqrt{3n}$$

A typical value of D/R is 4.6/1, corresponding to $n = 7$. For a regular grid of base sites packed in a hexangular grid, only certain values of n are possible: 3, 4, 7, 9, 12, 13 etc.; these correspond to evaluating:

$$n = i^2 + j^2 + ij$$

for non-negative integer values of i and j.

The system designer must decide what speech quality is required and choose the C/I objective. For example, experience in simulations, subjective tests, field trials, and early operational systems at 850 MHz indicates that a 90th percentile equal to or greater than 17 dB median C/I in an urban propagation environment will achieve a user acceptance goal of "good" or higher by the majority of telephone users [see Report 319, § 3.1.1 and 3.1.2]; systems for dispatch or private usage can be designed for a lower objective. During early growth phases when cells are relatively large and horizon effects limit interference, a 7-channel set re-use pattern is usually adequate, using conventional omnidirectional antennas; this assumes that no more than one or two interfering sites provide signals above the threshold level at any specific point in a base station's coverage area.

As growth to a more densely packed system takes place, either a larger channel re-use pattern (e.g. 12 sets) can be used, or a change-over to directional antennas for transmit and/or receive with a "sector" channel assignment pattern can be implemented. Arrangements using both 60° and 120° sectors have been designed; for a given n value, use of a sector assignment plan with directional antennas increases C/I by up to 5 dB (120° sectors) or 8 dB (60° sectors). In any event, the system planner should be satisfied that the *a priori* objective is exceeded in both the mobile-to-base and the base-to-mobile directions. The mobile-to-base direction is more complicated because of the random location of the potential interferers, because of the mix of vehicular and portable transmitters with different powers, and because of the building penetration loss that the portable unit can encounter.

To accommodate varying user density over the area of service, the cell plan should allow for different size cells to coexist in a system at the same growth stage. This generally means a doubling of the number of channel sets into which the allocation must be divided. Administrations should allow for this if the largest city or populated area is to grow to the divided-cell stage.

If the cellular channel plan avoids adjacent channels at the base station sites, the frequency deviation can be increased to enable closer re-use, resulting from an improved protection ratio.

Private dispatch systems which can handle traffic with a blocked-calls-queued strategy can be efficient with a smaller allocation than can mobile telephone systems.

3.2 *Co-channel interference experienced by stationary units*

Stationary units will not experience multipath fading as a loss in speech quality, resulting from rapid movement through the fading pattern, as mobile units do; rather, they will experience a very large number of points where the wanted signal has faded and the channel is unusable because of co-channel interference. In addition, shadowing will result in areas in which this problem is more severe due to a reduced local mean signal level.

The probability of co-channel interference, $P(s_1 \leqslant ps_2)$ for this case of simultaneous fading and shadowing with an uncorrelated wanted signal and a single interferer, has been calculated [French, 1979] as shown in Fig. 1.

Re-use distance ratios calculated using Fig. 1 and an inverse fourth power propagation law to give particular values of interference probability at the cell edge are shown in Table I, for protection ratios, P, of, for example 8 and 12 dB and shadowing standard deviations, σ, of 6 and 12 dB. Both fading and shadowing were included in the calculation.

Other values of protection ratio that may arise in particular systems should be used with Fig. 1 and the inverse power propagation law to find the corresponding re-use distances. Note that hand-off techniques may provide some diversity against fading, which would reduce the probability of call cut-off.

3.3 *Other comments*

3.3.1 It should be noted that in situations where it is intended to transmit a single message to a large number of vehicles distributed over several cells, the efficiency of frequency utilization is reduced for the duration of that message. Further studies are needed to determine the effect on spectrum efficiency of combining private and public systems.

3.3.2 Among the methods used to exchange channel control signals (channel assignment, dialling, etc.) are:

- the exchange of control signals over channels which can also be used as communication channels;
- the provision of channels dedicated either to control or communication but not both.

Both methods subtract from the total traffic capacity of the system. The choice between the above methods depends primarily on the amount of signalling traffic. In high capacity systems, the channels may be more efficiently utilized if the control channels are dedicated and are capable of being divided into the sub-sets of paging channels and access channels.

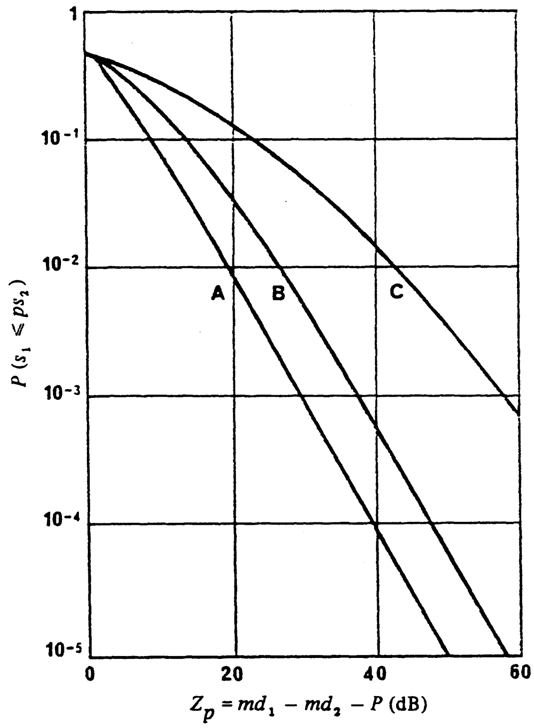


FIGURE 1 – *Probability of co-channel interference (with Rayleigh fading and log-normal shadowing)*

Curves A: σ = 0 dB
B: σ = 6 dB
C: σ = 12 dB

s_1 : wanted signal level (V)
s_2 : interfering signal (V)
p : protection ratio of modulation system
$P = 20 \log_{10} p$
md_1 : area mean level of wanted signal (dB)
md_2 : area mean level of interfering signal (dB)
σ : standard deviation of the shadowing
$Z_p = md_1 - md_2 - P$

TABLE I – *Re-use distance ratio (D/R)*

$P(s_1 \leqslant ps_2)$	σ = 6 dB		σ = 12 dB	
	P = 8 dB	P = 12 dB	P = 8 dB	P = 12 dB
0.5	2.6	3	2.6	3
0.1	4.7	5.6	7.3	8.9
0.03	6.6	8	13	16

3.3.3 If the method which provides control channels for control use only is chosen, control channel frequency assignment may be independent of communication channel cell size.

Two control channel frequency assignment methods are:

- assignment of a separate control channel for each communication cell;
- assignment of single control channel to cover a group of adjacent communication cells.

The choice between the above methods is made in accordance with call processing reliability and control traffic in each system.

3.3.4 Control channels are subject to similar C/I constraints as communication channels. To ensure that a system is not limited by its signalling capacity, the system designer should set aside an adequate number of signalling (control) channels. Preferably, this quantity should be dynamically changeable as the system grows.

4. Diversity

One or more diversity techniques to combat the effects of shadowing and multipath fading may be used, but are not absolutely necessary. The effect of such diversity is to increase significantly the efficiency of spectrum utilization [Lundquist and Peritsky, 1971]. The effects on system cost remain to be determined. While reception diversity at the base station is not a requirement of either a conventional or a cellular system, it can serve:

- to balance the C/I and C/N ratios in the mobile-base and base-mobile directions; and
- to improve the baseband S/N ratio for a given C/I or C/N ratio.

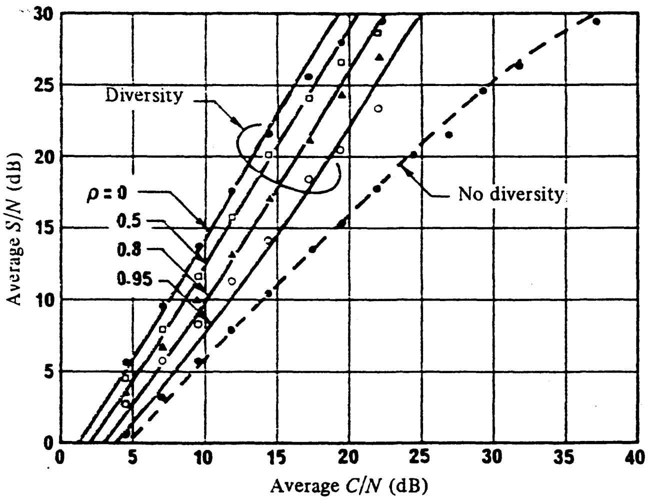
These factors are especially important for service to hand-held portables. At present, space diversity is the preferred method, currently realisable versions of frequency-diversity and time-diversity are not spectrally efficient, although research is continuing in techniques such as spread-spectrum and time-division re-transmission. The coherent combining methods (maximal ratio combining and equal-gain combining) achieve the best improvement compared with other methods. However, the equipment structure is complicated because of the requirement for a control function to ensure that the received signals are aligned in phase. In addition, the cost is high. On the other hand, the antenna switched method has a simple structure but voice quality signal suffers from switching noise and switching delay. A selection combining method with two diversity branches is more practical than two-branch coherent combining, although the former is a little inferior to the latter with respect to voice and data transmission. Switching noise generated in selecting the strongest signal level branch is reduced, and the voice signal quality is improved, by a post-detection selection combining technique. This technique is based on the selection of the baseband demodulated output of the diversity branch with the maximum reception level.

4.1 *Improved characteristics for thermal noise*

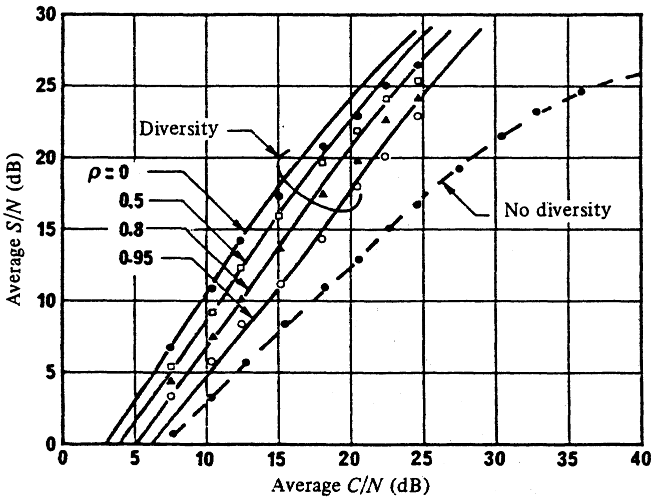
An example of experimental results [Suwa *et al.*, 1984] of thermal noise reduction in a voice signal using post-detection selection combining is shown in Fig. 2. The relative C/N is defined as the difference in average C/N required to obtain a given baseband S/N of 8 dB with diversity compared to the average C/N required to obtain that S/N without diversity. The relative C/N is more than 6 dB for an envelope correlation coefficient $\rho = 0$ and greater than 5 dB for $\rho = 0.5$.

4.2 *Improved characteristics for co-channel interference*

An example of experimental results [Suwa and Hattori, 1985] of co-channel interference reduction in voice signal using post-detection selection combining is shown in Fig. 3. The relative C/I is defined as the difference in average C/I required to obtain a given baseband S/I of 14 dB with diversity compared to the average C/I required to obtain that S/I without diversity. The relative C/I is more than 6 dB for an envelope correlation coefficient of $\rho = 0$ and greater than 5 dB for $\rho = 0.5$.



(a) B = 16 kHz



(b) B = 8 kHz

FIGURE 2 – *C/N versus S/N performance*

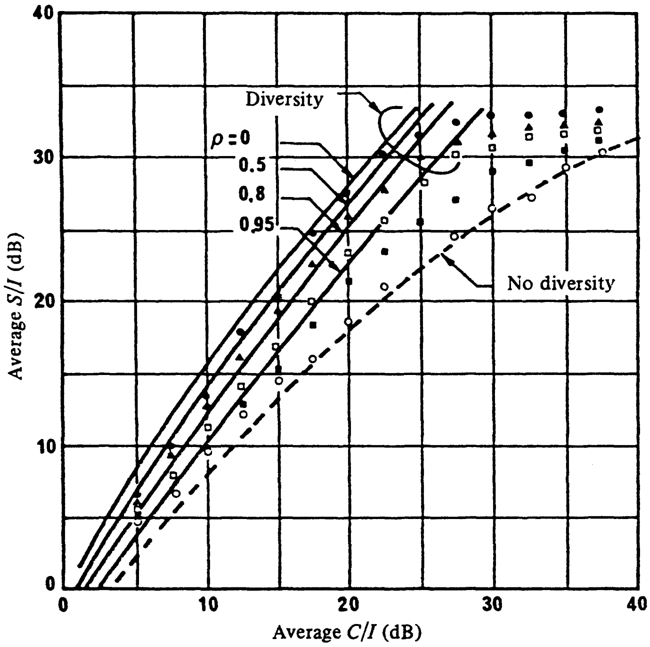
Condition:	– carrier frequency:	900 MHz band
	– IF filter bandwidth *B*:	16 and 8 kHz
	– fading rate:	34 Hz
	– standard modulation level:	$3.5/\sqrt{2}$ rad r.m.s. – B = 16 kHz
		$1.75/\sqrt{2}$ rad r.m.s. – B = 8 kHz

Compressor reference level is set equal to standard modulation level

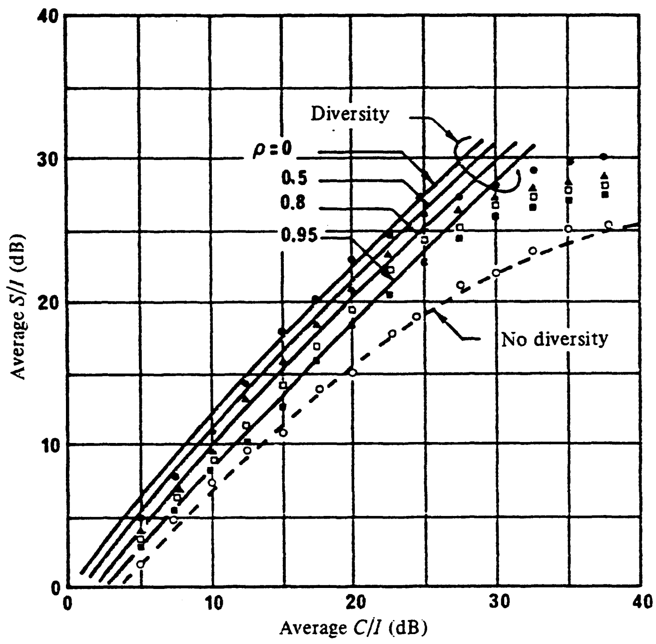
C/N is measured in 16 kHz and 8 kHz IF filter bandwidth

S/N is measured in 0.3-3 kHz baseband filter bandwidth

A 2 : 1 syllabic compandor is applied



a) B = 16 kHz



b) B = 8 kHz

FIGURE 3 – *C/I versus S/I performance*

Condition:	– carrier frequency	:	900 MHz band
	– IF filter bandwidth B	:	16 and 8 kHz
	– fading rate	:	34 Hz
	– standard modulation level	:	$3.5/\sqrt{2}$ rad r.m.s. – B = 16 kHz
			$1.75/\sqrt{2}$ rad r.m.s. – B = 8 kHz

Compressor reference level is set equal to standard modulation level

C/I is measured in 16 kHz and 8 kHz IF filter bandwidth

S/I is measured in 0.3-3 kHz baseband filter bandwidth

A 2 : 1 syllabic compandor is applied

5. Coping with vehicle movement

In a cellular system, mobile detection, location and registration as well as inter-cell switching are necessary when a mobile station moves across a cell boundary to:

- limit channel switching traffic;
- maintain adequate transmission quality;
- prevent the increase of co-channel interference;
- minimize the impairment caused by channel switching.

When the signal from a mobile unit engaged in a cell becomes inadequate, the system may be equipped to become aware of this fact and to effect a transfer (hand-off) from the original base station to a more appropriate one; conversely, the system may only locate the mobile unit and assign a base station at the beginning of a call, maintaining that assignment for the duration of the call. If a mobile unit is allowed to continue to use a base station when it moves out of that station's cell, the signal it encounters will have greater variability and lower average value. Similarly, since it can now move closer to the co-channel base stations serving other mobile units on the same frequency, the interference it encounters, and the interference it causes, will increase. Therefore, for any given quality of transmission, co-channel base stations would have to, in general, be spaced further apart if "hand-off" is not employed than they would have to be if it is; this adversely affects spectrum efficiency. For these reasons, hand-off is considered an essential feature of all cellular systems. One appropriate method to identify the radio cell from which a moving vehicle can best be served is the field-strength level of the carrier received from the mobile unit.

Field experience indicates that the voice quality of a cellular system is no better than the system's hand-off algorithm permits it to be. Too tight a control on signal level requires more hand-offs than necessary; this

- detracts from the capacity of the controller; and
- can cause frequent distraction to the users.

Too loose control, on the other hand, permits signal statistics to remain at unnecessarily low levels for long periods, can lead to high dropped-call probabilities, and can impair co-channel calls.

Mobile location registration may preferably be retained in the home exchange memory. Each base station broadcasts its unique identification code via the control channel. The mobile stations in the area keep this code in memory. When a new identification code is received by the mobile station, it can autonomously identify itself to the new serving area via a base station in that area. This information can be communicated to the home exchange (see Recommendation 624).

6. Intermodulation interference considerations

In a high capacity mobile telephone system using cells, it is necessary that intermodulation interference be minimized. However, because of the orderly spatial organization and the hand-off capability of cellular systems and as a result of new state-of-the-art transmitter/antenna coupling and combining arrangements used in cellular systems, intra-system intermodulation interference is considered to be controllable.

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REPORT 1156

DIGITAL CELLULAR PUBLIC LAND MOBILE TELECOMMUNICATION SYSTEMS (DCPLMTS)

(Study Programme 39A/8)

(1990)

1. Introduction

Digital cellular public land mobile telecommunication systems (DCPLMTS) are defined to be land mobile systems for voice and data services using digital cellular radio technology for the connection to the public switched telephone network (PSTN), integrated services digital network (ISDN) and public data networks (PDNs).

Part A of this report deals with the general principles of DCPLMTS and, in particular, addresses the rationale for digital cellular systems design. This part also provides a basic comparison with existing analogue cellular systems and discusses some architectural features of these systems.

The major characteristics of some DCPLMTS currently under development are presented in Part B of this report, together with a brief description of the current status of these systems and any unique features of their design.

PART A

GENERAL PRINCIPLES OF DCPLMTS

1. Introduction

Several DCPLMTS are currently under development. A Pan-European system called GSM is now under validation. The specification for a North American system is scheduled for completion by year end 1989. A Japanese system is also at an advanced stage of design. These systems are being designed for international operation and are expected to be widely implemented during the 1990s. In comparison, the on-going studies (Decision 69) necessary to specify future public land mobile telecommunication systems (FPLMTS) are not yet completed. It is expected that the FPLMTS will complement the DCPLMTS in the future. Thus it is timely to develop a report describing the key features of the emerging digital cellular public land mobile telecommunication systems.