Cellular Multimedia Network Management by Optimizing Efficiency, QoS Level and Capacity

Asadullah Malik[1], *Member, IEEE*, S.M. Aqil Burney[2], *Member, IEEE*
[1]Space & Upper Atmosphere Research Commission (SUPARCO), Karachi, Pakistan.
[2]Computer Science Department, University of Karachi, Pakistan
E-mail: asadmalik@ieee.org, burney@computer.org

***Abstract* – Growth in usage of mobile Internet services has complicated Quality of Service (QoS) management in cellular multimedia networks due to four objectives viz. maximum system efficiency in bandwidth utilization, enhanced user-perceived QoS level in terms of system protection ratio, maximum system capacity for accommodating ever increasing traffic load, and least handoff rate because every handoff interrupts the negotiated QoS parameters and thus affects the application performance to the extent that depends on period of induced interruption and type of application. In this paper, considering a GSM 900 based cellular multimedia network model, firstly the dependency of system efficiency on diversity of multimedia calls and handoff rate has been established; then having determined an optimized value of protection ratio, it is established that, regardless of protection ratio value, the system's capacity depends upon the employed MAC (Medium Access Control) protocol and handoff rate. Having confirmed numerical results by using LABVIEW 6.0 simulation software, it is concluded that, for any desired QoS level, the cellular multimedia network management would require intelligent optimization of system's efficiency and system's capacity that also depends upon employed MAC protocol and handoff rate.**

***Index Terms* - Cellular Multimedia Networks, GSM model, Efficiency, QoS and Capacity Optimization, Handoff Rate**

I. INTRODUCTION

Mobile Internet services are being provided by mobile multimedia networks using two contemporary standards viz. Information Mode (I-mode) that is used only in Japan, and Wireless Application Protocol (WAP) that is an open, bearer-independent and global standard. Customer satisfaction for users of WAP enabled Mobile Devices (WMDs) demands maximum efficiency while handling multimedia calls of diverse nature, enhanced user-perceived QoS level, increased system capacity, and minimum handoff rate. This paper aims to highlight that all four objectives can not be independently pursued; rather we need to trade off amongst them by intelligent optimization. Section II discusses the impact of handoff on QoS management; in section III, an optimum value of system protection ratio has been derived; section IV describes the parameters of a GSM 900 based cellular system model; section V establishes dependency of system efficiency on diversity of multimedia calls and handoff rate; in section VI, dependency of system capacity on handoff rate and employed MAC protocol has been established. Having confirmed numerical results by using graphical language based LABVIEW 6.0 simulation software, section VII summarizes the drawn conclusions.

II. IMPACT OF HANDOFF ON QoS MANAGEMENT IN MOBILE MULTIMEDIA NETWORKS

During inter-cell mobility of a WMD within the service area of a cellular system, if the quality of radio link between WMD and the serving Base Station (BS) deteriorates beyond acceptable level then, to maintain an on-going call, the channel assignment of WMD is switched under supervision of Mobile Telecommunication Switching Office (MTSO), either to another channel of serving BS or to a new BS, by performing a radio resource management task called "Handoff" [1]. During handoff, if the targeted BS has no available channel then handoff will fail resulting in forced termination of call, but this problem is controllable by prioritizing handoff calls over newly generated calls, however, this aspect has been addressed in a separate paper.

During every handoff execution, the end-to-end connection data path is incomplete for a short time thus resulting in interruption of the previously negotiated QoS and affecting the application performance depending on nature of application and period of induced interruption. Consequently, if the new BS can not provide previously negotiated QoS then we need to re-negotiate the end-to-end QoS parameters. During handoff, network resources are consumed for re-routing the call so more handoffs lead to more switching load due to additional control signals, and this is likely to deteriorate system efficiency (i.e. effectively used % of available bandwidth). Therefore, we need least number of quickly performed handoffs.

Handoff rate, however, is directly proportional to ongoing call holding time and mobility speed of WMD as well as inversely proportional to the cell size in the system [2].

III. OPTIMIZING SYSTEM PROTECTION RATIO

World Administrative Radio Conference, Geneva, 1979, defined protection ratio, denoted by **a** and measured in decibels as "Minimum value of wanted-to-unwanted signal ratio at the receiver input, measured under specified conditions, such that a specified quality of the wanted signal is achieved at the receiver output"[3]. In this definition, the term "specified conditions" means propagation conditions, type of modulation and employed multiple access format (MAC protocol) being used and required level of QoS.

Another definition of protection ratio (a) "as given in [4]" is "Minimum value of S/I at which 75% users of mobile communications express that the perceived QoS (measured at output of receiver) is either excellent or good in 90% of service area of cellular system".

Results for propagation in cellular systems over "Earth Plane" as derived by Norton and simplified by Bullington "as shown in [5]", indicate that signal power (S) received by a mobile unit is

$$S = \frac{W_s (h_{BS} h_M)^2 G_{BS} G_M}{R^4} \tag{1}$$

Where, W_s, h_{BS}, and G_{BS} are the transmitted power, antenna height above ground level, and gain of antenna of the serving BS respectively. R is the distance between serving BS and the mobile unit. Height above ground level of the antenna of mobile unit (e.g. a WMD) is h_M and its gain is G_M. Now, if the interfering BS is located at a distance (D) from the mobile unit, and is transmitting power W_i , then considering height (above ground level) of the interfering BS antenna as h_{Bi} and its gain as G_{Bi} , the interfering signal power (I) received at the mobile unit is given as follows

$$I = \frac{W_i (h_{Bi} h_M)^2 G_{Bi} G_M}{D^4} \tag{2}$$

Therefore,

$$\frac{S}{I} = \frac{W_S \; D^4 \; h_{BS}^2 \; G_{BS}}{W_i \; R^4 \; h_{Bi}^2 \; G_{Bi}} \tag{3}$$

Equation (3) indicates that S/ I (in other words protection ratio) can be maximized by maximizing the numerators or minimizing the denominators, however, doing so will not be feasible from the point of view of a mobile unit in the interfering co-channel cell because this would lead to minimizing its S/ I. Consequently, the most optimum value for protection ratio $a_{Optimum}$ will be

$$a_{Optimum} = (S/I)_{Optimum} = (D/R)^4 \tag{4}$$

IV. PARAMETERS OF GSM 900 SYSTEM MODEL

GSM 900 uses 890 -915 MHz for 124 uplinks and 935-960 MHz for 124 down links, and for multiple access format it uses a combination of FDMA and narrowband TDMA. Consider a seven-cell cluster (Nc=7) of a GSM900 cellular system supporting multimedia wideband and narrowband calls generated by the users of WAP based mobile Internet services. We will assume that system is homogenous, so that overall system performance is similar to the deduced isolated performance of a single cell known as "Marked Cell".

Assume that BSs are centrally located in all cells, which are of perfect hexagonal shape with cell radius (R) of 1.5 kms. Let total bandwidth available to system (B_t) be 50 MHz, and after deducting overhead of supervision/ set up channels etc, assume that we have 248 traffic channels each of 200 KHz bandwidth (B_c).

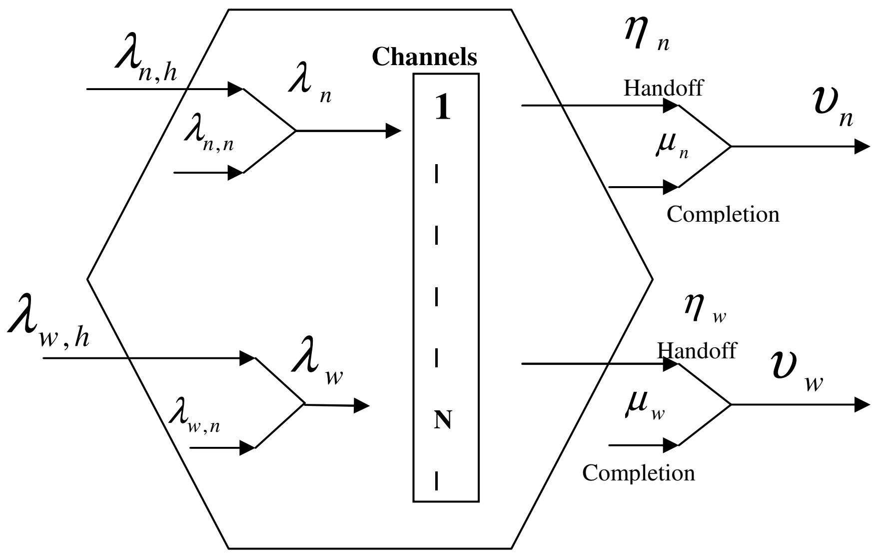
Each 200 KHz carrier is subdivided in to repeated narrowband TDMA frames having frame duration of 4.61 msec; while each frame is again subdivided in to 08 time slots each of 577 μ sec. Each time slot transmits data of 148 bits in bursts of 546.5 μ sec while remaining time of 30.5 μ sec is used for guard times. Therefore, each TDM channel occupies 200 KHz carrier for 577 μ sec after every 4.61 msec.

Assuming Fixed Channel Assignment (FCA) strategy, the 248 traffic channels get unequally distributed such that the "Marked Cell" gets total of 32 available channels (N). Assume that terrain and urbanization conditions have propagation constant $\alpha = 3.5$. Also, consider an average case that a WMD is moving at an average speed E[V] of 32 Kms/hour and is near the cell perimeter, so WMD is at distance R from serving BS and at a distance D from interfering BS of a co-channel cell [2].

We will not distinguish between the calls generated by a mobile user in the marked cell towards a user in any wired network connected by cellular system and vice-versa, and will also assume that all calls are generated by the mobile user. A mobile-to-mobile call will be considered simply as two independent calls.

In the marked cell, assume that for narrowband and wideband calls mean generation rate of new calls, as per Poisson distribution, be $\lambda_{n,n}$ and $\lambda_{w,n}$; mean handoff rate of narrowband and wideband calls be $\lambda_{n,h}$ and $\lambda_{w,h}$, mean call holding times are exponentially distributed with means, $1/\mu_n$ and $1/\mu_w$ and mean dwell times in the marked cell are exponentially distributed with means $1/\eta_n$ and $1/\eta_w$ respectively. Mean channel occupancy times in marked cell, for narrowband and wideband calls will be then exponentially distributed with means $1/\upsilon_n$ and $1/\upsilon_w$, where $\upsilon_n = \mu_n + \eta_n$ & $\upsilon_w = \mu_w + \eta_w$.

For easy comprehension of system model, the system parameters have been summarized along with graphical representation of "Marked Cell" as depicted in Figure 1.



Number of Cells In Cluster = N_c =7
Cell Area = A =2.598 R^2 = 5.85 Sq Kms
Average Speed of Mobile WMD = 32 Km/hr
System Bandwidth = B_t = 50 MHz
Traffic Channel Bandwidth = B_c = 200 KHz
Total Traffic Channels = M_a = 248
Traffic Channels for Marked Cell = N = 32
Number of Guard Channels = N_g = 08
Total frame Time = T = 4.61 msec
Total Time Slots for Traffic = M_t = 08
Slot Duration for Traffic = τ = 546.5 μ Sec
Propagation Constant = $\alpha = 3.5$

Figure 1 - GSM 900 Based System Model Indicating Marked Cell

V. SYSTEM EFFICIENCY'S DEPENDENCY ON HANDOFF RATE AND DIVERSITY OF CALLS

Assume that total number of cells in the system are N_t (where $N_t = N_C \times$ Number of clusters in the system). Also assume that handoff occurs in zero time during an ongoing k-type call where $k \in \{w, n\}$ and the considered k-type call consumes bandwidth b_k out of capacity of marked cell denoted as C_M. In view of system model parameters, C_M will be $C_M = NB_C$ = 6.4 MHz. Now, efficiency of cellular system (Є) "as shown in [6]" is the average total used bandwidth in system over total available system capacity,

$$\varepsilon = \frac{\underset{T->\infty}{Lim} \frac{1}{T} \int_T \sum_{k \in [i,j]} b_k \, dt}{\sum_{M=1}^{M=N_t} C_M} \tag{5}$$

Mobile user can select speed and direction of movement from uniform distributions [0, V_{Max}] and [0, 2π] respectively, however, for simplicity we assume that the WMD is moving at an average speed E[V] such that its dwell time in the marked cell denoted by t_{DM} is exponentially distributed with the mean proportional to the cell radius and inversely proportional to the E[V], then t_{DM} will be given as

$$t_{DM} = \pi A / E[V] L \tag{6}$$

As given in [7], A =2.598R^2 and L = 6R is the perimeter of marked cell, so for system parameters average dwell time is

$$t_{DM} = 1.36R / E[V] = 3.82 \text{ minutes} \tag{7}$$

Now, the mean number of handoffs (M_{H_k}) performed during call holding time (call duration) t_c can be given as

$$\text{Mean number of handoffs} = M_{H_k} = \frac{1}{\mu_k t_{DM}}$$

Putting value from equation (7) we get

$$M_{H_k} = \frac{E[V]}{1.36 \mu_k R} \tag{8}$$

Ignoring the possibility that the mobile user (e.g. WMD) will visit the same cell twice during the considered call; it is very clear from equation (7) that the WMD will traverse (1+M_{H_k}) cells during the call duration. Thus, the average reserved bandwidth for considered call (B_k) will be

$$B_k = b_k (1 + M_{H_k}) \tag{9}$$

If $\frac{\lambda_k}{\mu_k}$ is the offered traffic per mobile user of call type k, and average reserved bandwidth in system for all users of call type k is denoted by $\overline{B}$ whereas average total used bandwidth in the system for all users of call type k is denoted by $\overline{b}$ then in light of equation (5), system efficiency can be given as

$$\varepsilon = \frac{\overline{b}}{\overline{B}} = \frac{\sum_{k=1}^{K} A \frac{\lambda_k}{\mu_k} b_j (\textit{density of mobile users in marked cell})}{\sum_{k=1}^{K} A \frac{\lambda_k}{\mu_k} b_j (1+M_{H_k})(\textit{density of mobile users in marked cell})} \tag{10}$$

Table I - SYSTEM EFFICIENCY AS FUNCTION OF CELL RADIUS AND CALL HOLDING TIME (For E [V] = 8.88 m/sec (i.e. 32 Km/hour) & E [V] = 17.77 m/sec (i.e. 64 Km/hour)

Call Holding Time (i.e. 1/μ) in Seconds	Cell Radius in Meters		
	32000	**8000**	**1500**
200	96.0% & 92.3%	85.9% & 75.39%	53.4% & 36.48%
600	88.6% & 79.6%	66.2% & 49.49%	26.8% & 15.51%
1800	71.0% & 55.06%	37.9% & 23.45%	10.3% & 5.43%

In equation (10) if K=1, then as per equation (8), we get

$$\varepsilon^{(1)} = \frac{1}{1 + M_H} = \frac{1.36 R \mu}{1.36 R \mu + E[V]} \quad (11)$$

Let us calculate some numerical results of system efficiency from equation (11) and then simulate equation (11) as per system parameters. The numerical results are as given in table 1, for two different values of mobility speed of WMD; and the simulations of system parameters are given in Figure 2. Both numerical and simulation results help us to conclude that the system efficiency hyperbolically decreases with decrease in cell radius, increase in call holding time, and increase in mobility of WMD.

Now, in case of multimedia calls let there be two types of calls. Call type 1 is a wideband call having comparatively larger call holding time than call type 2 which is a narrowband call having lesser call holding time. Assume that the intensity of wideband calls is lesser than narrowband calls having high call intensity, such that the average total used bandwidth $\bar{b}$ remains same both for narrowband and wideband calls.

Let two calls have parameters $b_1 = bd$, $b_2 = b/d$, $\mu_1 = \mu/d$, $\mu_2 = \mu d$, $\lambda_1 = \lambda/2d^2$, and $\lambda_2 = \lambda d^2/2$ where d means amount of diversity between calls being handled by the cellular system. In system model we have only two types of calls, so for K=2 equation (10) becomes

$$\varepsilon^{(2)} = \frac{1.36R\mu}{1.36R\mu + \left(E[V] \frac{d + 1/d}{2} \right)} \quad (12)$$

Comparing equation (11) and (12) we note that system efficiency for K= 2 is inferior to efficiency for K= 1.

Same result is confirmed by simulation of equation (12), for the given system parameters, as given in Figure 3.

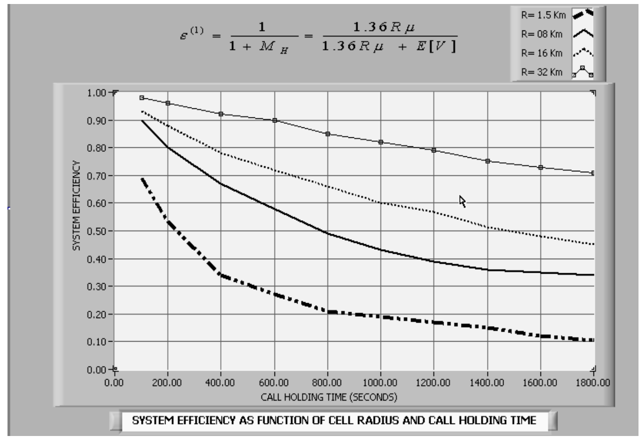


Figure 2 - Efficiency as a Function of Cell Radius and Call Holding Time

Therefore, system efficiency is inversely proportional to diversity of multimedia calls being handled by the system.

VI. SYSTEM CAPACITY'S DEPENDENCY ON PROTECTION RATIO, USED MULTIPLE ACCESS FORMAT AND HANDOFF RATE

Stallings has established in [8] that in cellular systems the Co-Channel Reuse Ratio (Q) is given as

$$Q = \frac{D}{R} = \sqrt{3N_c} \quad (13)$$

Now, from parameters of our system model we get $\frac{D}{R} = \sqrt{3*7} = 4.582$, and in view of equation (4) this will imply that for our system model the optimum protection ratio in dBs will be

$$a_{Optimum} = 10\log_{10}(440.77) = 26.44 \text{ dBs} \quad (14)$$

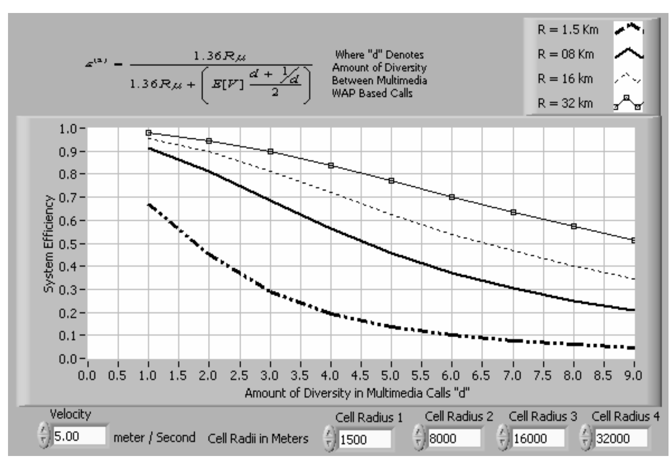


Figure 3 - System Efficiency as a Function of Call Diversity

Now, Hammuda has established in [3] that system capacity i.e. overall optimum spectral efficiency (η_C) measured in channels/MHz/Km^2 is given in terms of multiple access efficiency factor η_T as

$$\eta_{c_{optimum}} = \left(\frac{3}{A B_c \left(6 a_{Optimum}\right)^{2/\alpha}} \right) \eta_T \qquad (15)$$

Now, in system model we considered R = 1.5 Km to give A= 2.598 R^2 =5.85 Km^2, B_C = 0.2 MHz, and propagation constant (α) as 3.50, therefore, the above equation gives

$$\eta_{c_{optimum}} = \frac{0.833}{A} \eta_T = 0.142 \eta_T \qquad (16)$$

This means that overall system capacity will increase as we keep on decreasing cell size, whereas same is true for hand-off rate. This also implies that if we want to increase system capacity by decreasing cell size then it will result in deteriorated system efficiency due to more handoffs. Now, if we analyze the impact of multiple access formats on the optimized η_C, then in light of calculations made in [2], overall optimized capacity of our system model for various MAC protocols (FDMA, TDMA, CDMA) will be given as

$$\left. \begin{aligned} \eta_{c_{optimum\,FDMA}} &= 0.142 \left(\frac{B_c M_a}{B_t} \right) \\ \eta_{c_{optimum\,WB-TDMA}} &= 0.142 \left(\frac{\tau M_t}{T} \right) \\ \eta_{c_{optimum\,NB-TDMA}} &= 0.142 \left(\frac{\tau M_t B_u M_u}{T B_t} \right) \end{aligned} \right\} \qquad (17)$$

Multiple access efficiency factor for CDMA has to be lesser or equal to that for narrowband-TDMA. Now, GSM uses combination of FDMA and narrowband-TDMA [8], so

$$\eta_{c_{optimum\;GSM}} = \eta_{c_{optimum\,NB-TDMA}} \eta_{c_{optimum\,FDMA}} \qquad (18)$$

TABLE II – TYPICAL VALUES AND SYSTEM MODEL VALUES OF MAC EFFICIENCY FACTOR η_T FOR VARIOUS MAC PROTOCOLS

MAC Formats	**Typical η_T Values**	**System Model η_T Values**
FDMA	95%	99.2%
Wideband-TDMA	89%	94.8%
Narrowband-TDMA	67.5%	70.5%
GSM	67%	69.9%
CDMA	65%	≤ 70.5%

TABLE III - OPTIMUM CAPACITY FOR SYSTEM MODEL FOR VARIOUS CELL SIZES AND VARIOUS MAC PROTOCOLS

Cell Radii (Km)	**Optimum System Capacity $\eta_{c_{optimum}}$ For System Model Parameters**			
	FDMA	**WB-TDMA**	**NB-TDMA**	**GSM**
1.50	0.141	0.134	0.101	0.097
3.00	0.035	0.033	0.025	0.024
4.00	0.019	0.018	0.014	0.013

In narrow-band-TDMA the B_u is the bandwidth which a user can have access during its allotted time slot, and M_u is the number of users sharing the same time slot but having access to different frequency bands. Now, in view of our system parameters, the multimedia users can consume either one or two channels at a time. For calculation of numerical results let us assume an average case that users consume 1.50 channels resulting in B_u = 0.30 MHz. Now, as each user needs uplink as well as downlink channels for communication, therefore, M_u will be 124. Now, in light of equations (17), (18), we calculate the numerical results of η_T for various MAC protocols (i.e. multiple access formats) for our system parameters, and then compare calculated results with theoretical typical values of η_T given by Hammuda in [3]. The said comparison is given in Table 2.

Now, system model has channel bandwidth of 0.2 MHz, so let us calculate the optimum system capacity in channel / MHz / Km^2 for varying cell size and MAC formats. For example, for marked cell and FDMA scheme it would be,

$$\eta_{c_{optimum}} = \frac{0.833}{A} * \eta_T = 0.142 * 0.992 = 0.141$$

Other calculations are depicted as follows in Table 3. These numerical results given in Table 3 have been confirmed by LABVIEW 6.0 simulation software, and simulation results are depicted in Figure 4.

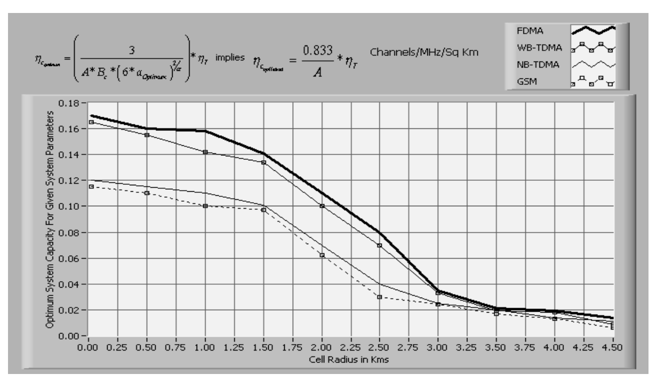


Figure 4 - Optimum System Capacity as a Function of Cell Radius and Employed MAC Format

VII. SUMMARY OF CONCLUSIONS

For QoS management in cellular multimedia cellular systems, it has been analyzed that how rate of handoff will have impact on system's efficiency for bandwidth utilization and system's capacity for maintaining demand-supply equilibrium in face of ever-increasing traffic load. Summarized conclusions of conducted research are as follows:

(a) Bandwidth efficiency of a cellular system is directly proportional to cell radius but inversely proportional to call holding time as well as to speed of WMD. Therefore, when handoff rate will increase then it will have adverse effect on bandwidth efficiency of the cellular system.

(b) Bandwidth efficiency of a cellular system is inversely proportional to diversity of multimedia calls being handled by the system. Therefore, bandwidth efficiency of system deteriorates when it handles mobile Internet services, as compared to the scenario when it handles only voice calls.

(c) Optimum protection ratio for any cellular system is given as $10\log_{10} Q^4$ dBs, where Q is co-channel reuse ratio given as $Q = D / R = \sqrt{3N_C}$

(d) Regardless of protection ratio and cell size, the system capacity decreases as we move from FDMA to TDMA, to GSM and CDMA as chosen MAC protocol out of generally used multiple access formats (FDMA, TDMA, GSM that is combination of FDMA and TDMA, CDMA).

(e) System capacity (i.e. overall spectral efficiency measured in Erlangs or Channels per MHz per Km^2) is inversely proportional to the cell radius, and user perceived QoS level in terms of protection ratio. So, when we try to increase system capacity by using micro or pico cells then it leads to higher handoff rate that translates in to requirement of more control channels for monitoring/setup/supervision functions thus resulting in to reduced system efficiency (Є).

Therefore, for QoS management in cellular multimedia networks, we need to perform intelligent optimization of system's efficiency, desired user-perceived QoS level in terms of protection ratio, as well as system's capacity which is further dependent on used MAC format and handoff rate.

REFERENCES

[1] N.D. Tripathi, J.F. Reed, and H.f. Vanlandingham, "Handoff in Cellular Systems", IEEE Personal Communications, December 1998

[2] Asadullah Malik, "Role of Handoff in QoS for WAP Based Mobile Internet Services", M.Sc. Thesis, Sir Syed University of Engineering & Technology (SSUET), Karachi, Pakistan, 2003

[3] Husni Hammuda, "*Cellular Mobile Radio Systems: Designing Systems for Capacity Optimization",* John Wiley & Sons Ltd, West Sussex, England, 1997

[4] MacDonald, V. H, "Advanced Mobile Phone Services: The Cellular Concept", Bell Systems Technical Journal, January 1979.

[5] Reudink D.O, "Properties of Mobile Radio Propagation Above 400 MHz", IEEE Transactions on Vehicular Technology, November, 1974

[6] A.G.Valko and A.T. Campbell, [Online] "An Efficiency Limit for Cellular Mobile Systems", Available: http://whitepapers.zdnet.co.uk/0,39025945,60021308p-39000518q,00.htm, 15 November 2003 [date accessed]

[7] D. Hong and S. Rappaport, "Traffic Model and Performance Analysis for Cellular Mobile Radio Telephone Systems with Prioritized and Non-prioritized Handoff Procedures", Revised Tech Report No. 773 dated 1st June, 1999, State University of N.Y, USA

[8] Stallings W., "*Wireless Communications and Networks",* Pearson Education Ltd, Delhi, India, 2002