Optimized Channel Assignment Scheme for TETRA Networks

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Abstract: - This paper presents a channel management scheme in a Tetra Network based on a two-layer cellular architecture which optimizes the blocking probability performance of Low Moving Terminals (LMT) in a congested urban area. The lower layer of the proposed architecture is based on a microcellular solution, for absorbing the traffic loads of both the handoff and new calls of the Low Moving Terminals (LMT). The higher layer is based on a macro-cell umbrella solution, for absorbing the traffic load of the handoff and new calls of the Fast Moving Terminals (FMT). The results show that using the optimum number of channels in each layer, the QoS of the HMT is optimized having the minimum effect on the QoS of the LMT.

Key-Words: - Mobile communication, Tetra Network, Channel Assignment Scheme, Velocity

1 Introduction

Mobile communications systems experience a rapid increase in the number of subscribers, which places extra demands on their capacity. This is especially true for Tetra networks, which have been experiencing a tremendous growth rate in recent years and have become the leading digital cellular standard for Security Forces. This growth rate increases the demand of the involved reliable and efficient operations. The most serious problem that arises in these systems when a terroristic event happens, is that the call blocking probability is increased. This happens because in the area the event happens many users are concentrating there.

A great effort has been spent in order to study the channel management schemes in order to minimize the involved blocking probability [2]. Each carrier in the TETRA system accommodates four time slots which represent the physical channels available. These physical channels are shared between a number of logical channels which carry both traffic and signaling information. The handoff blocking probability is considered to be more important than the blocking probability of new calls because the call is already active and the QoS is more sensitive for the handoff calls.

The examined model adopts a traffic analysis for cellular mobile networks with prioritized handoff procedure. By taking into account that C are the available channels in every microcell and the priority technique for handoff calls is realized by assigning guard channels (C_h) exclusively for handoff calls, the remaining ($C-C_h$) channels are shared both by new and handoff calls. The following assumptions, without affecting the results, are considered: a) the terminals are characterized as LMT or HMT according to the speed they move. b) Homogenous traffic, same capacity and same mean holding time T_h are considered in all microcells. New and handoff calls of LMT are generated in the area of microcell according to a Poisson point process, with mean rates of Λ_R^L, Λ_{Rh}^L respectively, while new calls and handoff calls of HMT are generated with mean rates of Λ_R^H, Λ_{Rh}^H per cell. The relative mobilities are defined as:

for LMT: $\quad a_L = \Lambda_{Rh}^L \left(\Lambda_{Rh}^L + \Lambda_R^L \right)$ (1)

for HMT: $\quad a_H = \Lambda_{Rh}^H \Big/ \left(\Lambda_{Rh}^H + \Lambda_R^H \right)$ (2)

also it is defined a coefficient for LMT:

$$k_L = \left(\Lambda_{Rh}^L + \Lambda_R^L\right)\Big/\left(\Lambda_{Rh}^L + \Lambda_R^L + \Lambda_{Rh}^H + \Lambda_R^H\right) \qquad (3)$$

and for HMT

$$k_H = \left(\Lambda_{Rh}^H + \Lambda_R^H\right)\Big/\left(\Lambda_{Rh}^L + \Lambda_R^L + \Lambda_{Rh}^H + \Lambda_R^H\right) \qquad (4)$$

The offered load per cell is

$$Toff = \left(\Lambda_{Rh}^L + \Lambda_R^L + \Lambda_{Rh}^H + \Lambda_R^H\right)\Big/\mu_H \qquad (5)$$

where $\mu_H = 1/T_H$ and T_H is the channel holding time.

2 Analysis of the Existing Model with Prioritized Handoff Procedures

Let n be the number of microcells in the microcellular area. The total offered load in the system is:

$$T_{off}^{tot} = n \cdot T_{off} \qquad (6)$$

and the total number of channels in the system is

$$C_s = n \cdot C \qquad (7)$$

The steady state probabilities that j channels are busy in every microcell, can be derived from [3]

$$P_j = \begin{cases} \dfrac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^j}{j!\mu_H^{\,j}} P_0 \\[4mm] \dfrac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{C-C_h}\left(\Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{j-(C-C_h)}}{j!\mu_H^{\,j}} P_0 \end{cases}$$

$$\begin{aligned} &for \;\; j = 1,2,...,C-C_h \\ &for \;\; j = C-C_h+1,...,C \end{aligned} \qquad (8)$$

where:

$$P_0 = \left[\sum_{k=0}^{C-C_h} \frac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^k}{k!\mu_H^{\,k}} \right. \qquad (9)$$

$$\left. + \sum_{k=C-C_h+1}^{C} \frac{\left(\Lambda_R^L + \Lambda_R^H + \Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{C-C_h}\left(\Lambda_{Rh}^L + \Lambda_{Rh}^H\right)^{k-(C-C_h)}}{k!\mu_H^{\,k}} \right]^{-1}$$

The blocking probability (P_B) for a new call (either HMT or LMT) per microcell is the sum of probabilities that the state number (j) of the microcell is $\geq (C-C_h)$. Hence:

$$P_B = \sum_{j=C-Ch}^{C} P_j \qquad (10)$$

The probability of handoff attempt failure P_{fh} is the probability that the state number of the microcell is equal to C. Thus:

$$P_{fh} = P_C \qquad (11)$$

The P_{fh} of HMT is:

$$P_{fh}^{HMT} = \left(\Lambda_{Rh}^H \Big/ \left(\Lambda_{Rh}^L + \Lambda_{Rh}^H\right)\right) P_{fh} \qquad (12)$$

The mean call blocking probability (P_{nl}) for the microcellular layer (n microcells), considering new and handoff calls of LMT and HMT, is defined as:

$$P_{nl} = \frac{\displaystyle\sum_{i=1}^{n}\left(\left(\Lambda_R^H(i) + \Lambda_R^L(i)\right)\cdot P_B^m(i) + \left(\Lambda_{Rh}^H(i) + \Lambda_{Rh}^L(i)\right)\cdot P_{fh}(i)\right)}{\displaystyle\sum_{i=1}^{n}\left(\Lambda_R^L(i) + \Lambda_R^H(i) + \Lambda_{Rh}^H(i) + \Lambda_{Rh}^L(i)\right)}$$

(13)

The proposed channel management scheme for the Tetra Network based on a two-layer architecture is introduced in order to dedicate different layers to different types of subscribers, according to their speed, in the same geographical area. The implementation of the different layers doesn't require any special hardware setting but only new radio parameters in the existing software. This approximation introduces a two-layer architecture, the lower microcellular layer and the higher, the "Umbrella layer", which is implemented by a "macrocell" [4],[5]. Figure 1 shows the proposed architecture. In addition, the microcell cell layer services handoff calls of HMT and new calls of HMT, homogeneous traffic is considered in all microcells and umbrella cell, and the T_h is the same for the microcells and the umbrella cell.

Let n be the number of microcells that consist the microcellular layer and C_{mi} the number of channels that assigned to every microcell. Let C_S be the total number of channels in the system and C_{ma} the channels assigned to macrocell to serve both handoff calls of HMT and new calls of HMT. Hence:

$$C_S = nC_{mi} + C_{ma} \qquad (14)$$

The handoff blocking probability is considered to be more important than the blocking probability of new calls because the call is already active and the QoS is more sensitive for the handoff calls. So in the microcellular layer, priority is given to handoff attempts by assigning guard channels (C_{hmi}) exclusively for handoff calls of LMT among the C_{mi} channels in a cell. The remaining (C_{mi}-C_{hmi}) channels are shared by both new calls of LMT and handoff calls of LMT [3]. Similarly, in the higher layer (macrocell), priority is given to handoff attempts of HMT by assigning C_{hma} guard channels exclusively for handoff calls of HMT among the C_{ma} channels in umbrella. The remaining (C_{ma}-C_{hma}) channels are shared by both new calls of HMT and handoff calls of HMT. The mean rate of generation of handoff calls of HMT is Λ_{Rh}^H per cell and the mean rate of generation of new calls of HMT is Λ_R^H. So the mean rate generated in the umbrella is

$n \cdot (\Lambda_{Rh}^{H} + \Lambda_{R}^{H}).$
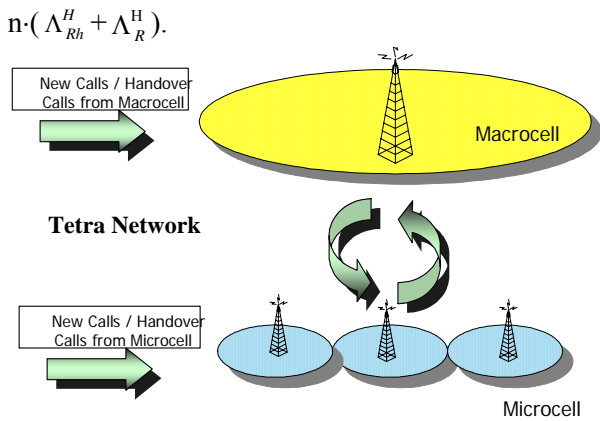
Figure 1: Proposed two-layer architecture

In the proposed architecture, a ratio C_{ma}/C_S is assigned according to α_L, α_H, α_{HL} and T_{off}^{tot}, contributing to the improvement of call blocking probability of HMT (blocking probability of the higher layer) with the smallest bad effect on the QoS of LMT. Each time a channel must be allocated in the micro-cell, the existing conditions of offered load in the system are checked. The suitable number of channels that can be assigned in the micro-cell is

determined depending on the presented traffic. The algorithm continues the process for different values of C_{ma}/C_S. The results are compared with those of a simple model in which the higher level of umbrella-cell does not exist. In this model there are n available channels in each microcell. 10% of them are used exclusively for handoff calls, while the rest of them are shared randomly by both the new and handoff calls.

The steady state probabilities that j channels are busy in a microcell can be derived from figure 2 [2],[3]

$$P_j^{mi} = \begin{cases} \dfrac{\left(\Lambda_R^L + \Lambda_{Rh}^L \right)^j}{j! \mu_H{}^j} P_0^{mi} \\[2mm] \dfrac{\left(\Lambda_R^L + \Lambda_{Rh}^L \right)^{Cm-Chm} \Lambda_{Rh}^{L}{}^{j-(Cm-Chm)}}{j! \mu_H{}^j} P_0^{mi} \end{cases} \quad (15)$$

$j = 1, 2, ..., C_{mi} - C_{hmi}$

$j = C_{mi} - C_{hmi} + 1, ..., C_{mi}$
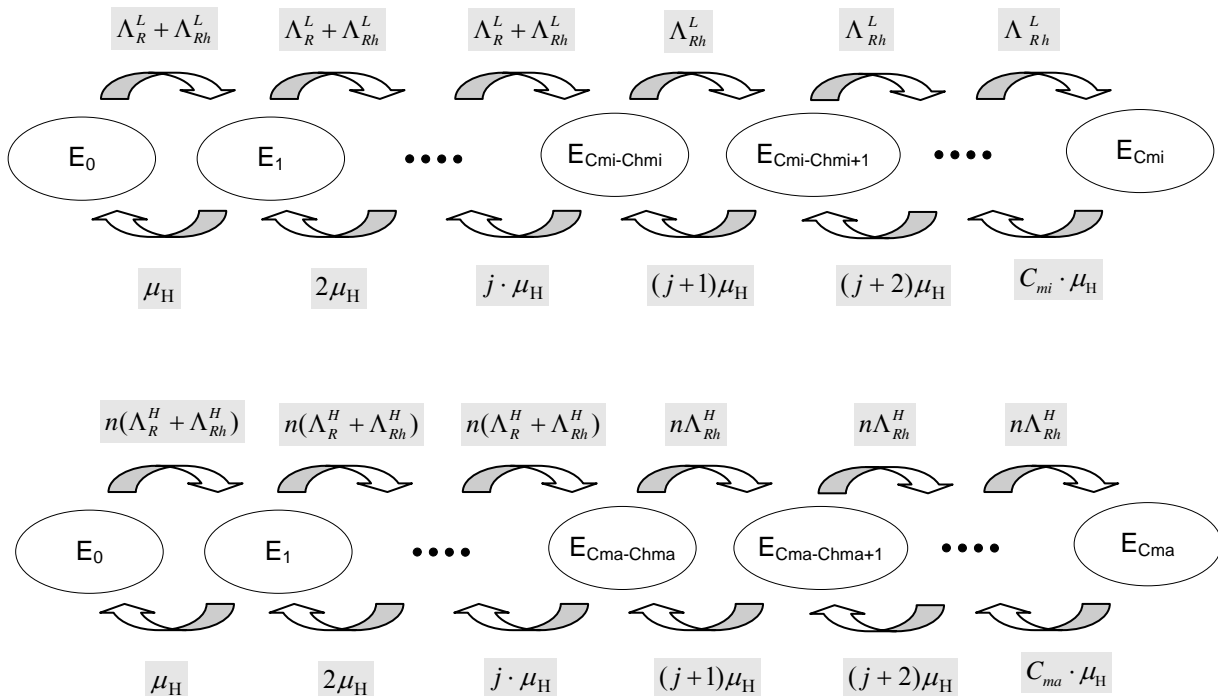
Figure 2: State Transition diagram for: (a) every microcell and (b) umbrella cell of proposed architecture

where

$$P_0^m = \left[\sum_{k=0}^{Cmi-Chmi} \frac{\left(\Lambda_R^L + \Lambda_{Rh}^L\right)^k}{k!\,\mu_H^k} + \right.$$

$$\left. \sum_{k=Cmi-Chmi+1}^{Cmi} \frac{\left(\Lambda_R^L + \Lambda_{Rh}^L\right)^{Cmi-Chmi} \Lambda_{Rh}^{L\,k-(Cmi-Chmi)}}{k!\,\mu_H^k} \right]^{-1} \quad (16)$$

The blocking probability for a new call of LMT per microcell is the sum of probabilities that the state number of the microcell is $\geq C_{mi}-C_{hmi}$. Hence:

$$P_B^{mi} = \sum_{j=C_{mi}-Ch}^{C_{mi}} P_j^{mi} \quad (17)$$

The probability of handoff attempt failure P_{fh}^{mi} is the probability that the state number of the microcell is equal to C_{mi}. Thus:

$$P_{fh}^{mi} = P_C^{mi} \quad (18)$$

For the umbrella cell, the steady state probabilities that j channels are busy can be derived from figure 2 [2],[3]:

$$P_j^{ma} = \begin{cases} \dfrac{\left(\Lambda_R^H + \Lambda_{Rh}^H\right)^j}{j!\,\mu_H^j} P_0^{ma} \\[4mm] \dfrac{\left(\Lambda_R^H + \Lambda_{Rh}^H\right)^{Cma-Chma} \Lambda_{Rh}^{H\,j-(Cma-Chma)}}{j!\,\mu_H^j} P_0^{ma} \end{cases}$$

$$j=1,2,...,C_{ma}-C_{hma}$$

$$\quad (19)$$

$$j=C_{ma}-C_{hma}+1,...,C_{ma}$$

where

$$P_0^{ma} = \left[\sum_{k=0}^{Cma-Chma} \frac{\left(\Lambda_R^H + \Lambda_{Rh}^H\right)^k}{k!\,\mu_H^k} + \right.$$

$$\left. \sum_{k=Cma-Chma+1}^{Cma} \frac{\left(\Lambda_R^H + \Lambda_{Rh}^H\right)^{Cma-Chma} \Lambda_{Rh}^{H\,k-(Cma-Chma)}}{k!\,\mu_H^k} \right]^{-1} \quad (20)$$

The blocking probability for a new call of HMT per cell is the sum of probabilities that the state number of the umbrella cell is $\geq C_{ma}-C_{hma}$. Hence:

$$P_B^{ma} = \sum_{j=C_{ma}-Ch_{ma}}^{C_{ma}} P_j^u \quad (21)$$

The probability that a handoff call will be blocked in the umbrella cell is P_{fh}^{ma} and is the probability that state number of the cell is equal to C_{ma}. Thus:

$$P_{fh}^{ma} = P_{Cma} \quad (22)$$

The QoS the microcellular layer (n microcells), is defined as:

$$QoS_{LMT} = \frac{\sum_{i=1}^{n} \left(\left(\Lambda_R^L(i)\right)\cdot P_B^{mi}(i) + \Lambda_{Rh}^L(i)\cdot P_{fh}^{mi}(i)\right)}{\sum_{i=1}^{n} \left(\Lambda_{Rh}^L(i) + \Lambda_R^L(i)\right)} \quad (23)$$

For the umbrella layer the QoS of HMT is defined as:

$$QoS_{HMT} = \frac{\sum_{i=1}^{n} \left(\left(\Lambda_R^H(i)\right)\cdot P_B^{ma}(i) + \Lambda_{Rh}^H(i)\cdot P_{fh}^{ma}(i)\right)}{\sum_{i=1}^{n} \left(\Lambda_{Rh}^H(i) + \Lambda_R^H(i)\right)}$$

$$\quad (24)$$

Therefore, the QoS for handoff calls especially for HMT must be guaranteed while allowing high utilization of channels. The objective of the proposed architecture is to guarantee the required handoff blocking probability for HMT.

3 Results

Figure 3 and 4 present the performance of call blocking probability for new and handoff calls of LMT respectively. Figure 5 and 6 present the performance of call blocking probability for new and handoff calls of HMT respectively. Figure 7 and 8 present the QoS for LMT and HMT.

In all figures, curve (i) represents the performance of a typical tetra network for $C_s=240$ according to a traffic model analysis based on erlang b model (OLA-EB). Curve (ii) represents the performance of a tetra network for $C_s=240$ according to a traffic model analysis with prioritized handoff procedure (OLA-GC). In these cases, there is no umbrella layer and all the involved calls are served by microcells. The other curves show the performance of a tetra network based on the the proposed architecture for $C_s=240$, where new and handoff calls of HMT are served by the umbrella layer and the new and handoff calls of LMT by the microcellular layer. In curve (iii): $C_{ma}/C_S=28/240$, in curve (iv): $C_{ma}/C_S=48/240$ and in curve (v): $C_{ma}/C_S=72/240$.
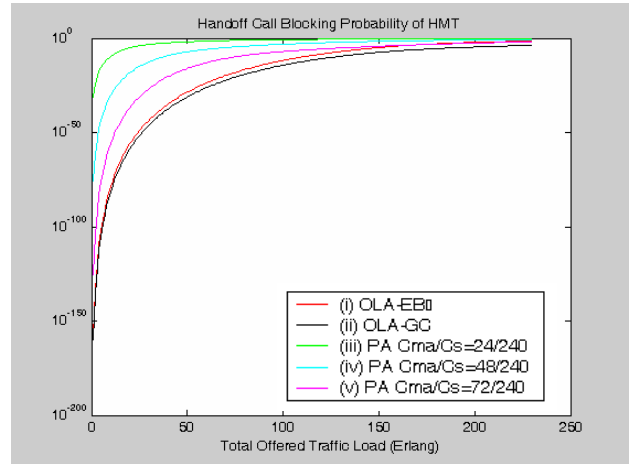
In the performed simulation, the number of microcells is considered to be n=3, without affecting the generality of the model. The following parameters are also considered: $C_h=0.2C$, $T_H=75s$, $\alpha_L=0.6$, $\alpha_H=0.4$, $k_L=0.6$ and $k_H=0.4$and $\alpha_{HL}=0.46$. Using these values and $0\leq T_{off}^{tot} \leq230$ erlangs, the Λ_R^L, Λ_{Rh}^L, Λ_R^H, Λ_{Rh}^H are calculated.

Curves show an improvement in the QoS of LMT as a result of using the proposed architecture, as well as adjusting the ratio for different values of C_{ma}/C_S. This is very important in security forces
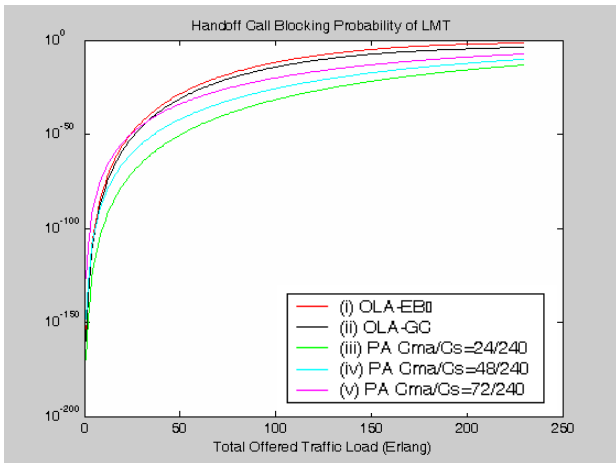
events (e.g terroristic attacks) where many security forces concentrate on a small area and move with low speed.
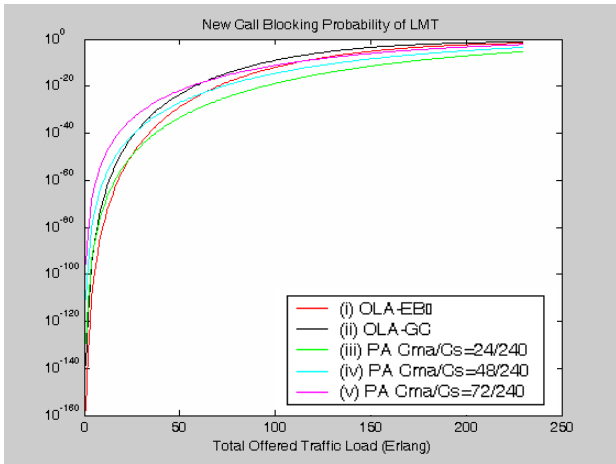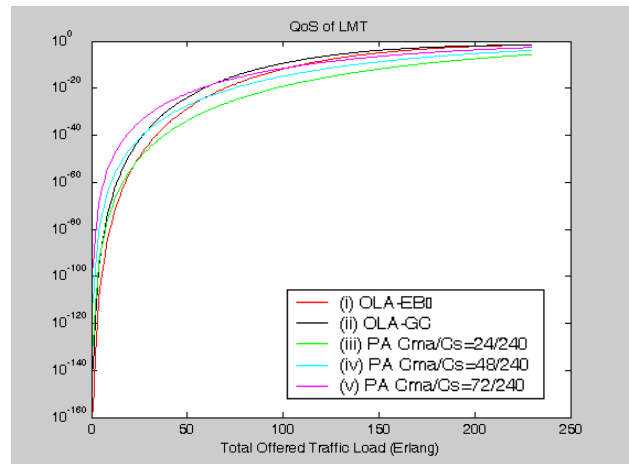
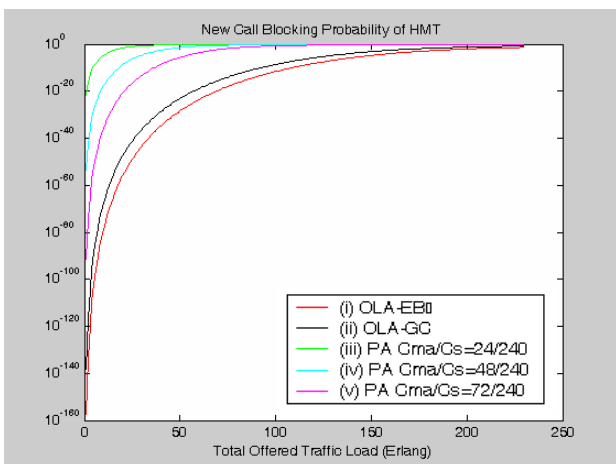**Figure 3:** Call Blocking Probability of New Calls of LMT

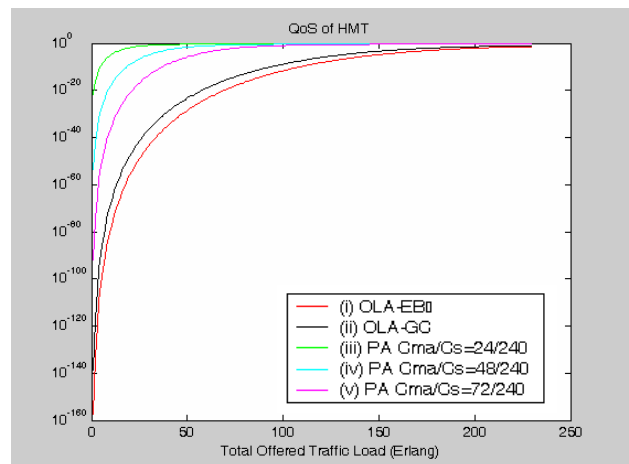**Figure 4:** Call Blocking Probability of Handoff Calls of LMT

Figure 5: Call Blocking Probability of New Calls of HMT

Figure 6: Call Blocking Probability of Handoff Calls of HMT

Figure 7: QoS of LMT

Figure 8: QoS of HMT

4 Conclusion

A new two-layer architecture has been proposed for TETRA Networks in order to achieve better QoS for LMT in areas that a terroristic event happened. In this architecture, the umbrella cell philosophy has been introduced to serve new and handoff calls of HMT. Moreover, according to the obtained results, QoS of LMT has been optimized having the minimum negative effect on the QoS of HMT.

References:

[1] K. Ioannou, S. Louvros, I. Panoutsopoulos, S. Kotsopoulos and G. K. Karagiannidis, Member IEEE, "Optimizing the Handover Call Blocking Probability in Cellular Networks with High Speed Moving Terminals", IEEE Communications Letters, Vol 6, No. 10, October 2002.

[2] T. S. Rappaport, "*Wireless Communications*", July 1999, ISBN 0-13-375536-3**.**

[3] D.Hong and S.S. Rappaport: "Traffic model and performance analysis for cellular mobile radio telephone systems with prioritized and non prioritized handoff procedures", *IEEE Trans.*, 1986, VT-35, pp 77-92

[4] D.Berreti, "Default set of BSS Parameters for Cosmote Network and set of BSS parameters for umbrella cells", Nokia Productivity Services, Tech. Rep, Nokia Telecommunications, 7.8.1998, pp 2-16.

[5] J. Zander, S-L Kim, "*Radio Resource Management for Wireless Networks*", 2001, ISBN1-58053-146-6.