# Resource Reservation and Utility based Rate Adaptation in Wireless LAN with Slow Fading Channels

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***Abstract*— Recently there is a growing interest in the adaptive multimedia networking where the bandwidth of an ongoing multimedia flow can be dynamically adjusted. In this paper the attention is focused on the management of mobility independent services. The considered class of service has been the MIP class, defined in Integrated Services for mobile wireless environment. In order to offer an adaptive QoS (soft QoS) increasing the total wireless system utilization, a rate adaptation algorithm has been considered. The valued algorithm is based on user utility function and its target is to maximize this function. The mobility of host can impact on number of handoff and on channel states (fading), so the rate adaptation accounts the degradation channel state conditions. An algorithm of admission control has been considered too in order to regulate the access to wireless multimedia network. The admission control can use the pre-reservation phase among the visited cells from mobile hosts for MIP. The performance evaluations of the wireless system have been evaluated in terms of total bandwidth utilization for MIP services, average user utility perceived by mobile users and system outage probability.**

***Keywords*— Admission control, adaptive bandwidth allocation, utility function, Markov model, fading channels, pre-reservation.**

## I. INTRODUCTION

There has been a rapid growth in popularity of wireless data services and an increasing maturity of wired multimedia networks so, extending multimedia services into wireless network is inevitable. Wireless communications pose special problems, such as limited bandwidth and high error rate, that do not exist in wired networks; in addition, the dynamics of physical channels cause fluctuations in received signals; for these reasons, deterministic service guarantees and bandwidth allocation, commonly used in wired networks, become inadequate for dealing with wireless communications. User mobility has an important impact on QoS parameters of real-time applications and the existing protocols, as proposed in [1], must be extended in order to manage host's mobility. This can be handled by using the MRSVP protocol, which is based on active and passive reservations and capable to pre-reserve an amount of bandwidth for MIP flows to guarantee the desired QoS during hand-off events.

Since the dynamics of the resources in mobile computing environments is much more severe than in wireline environments, it is perceived in the scientific community the need to provide effective mechanisms for adaptation at multiple bandwidth levels

There different work in literature that account the adaptation of the resource in wireless environment and base the criteria of the bandwidth adaptation on different indexes as the min-max fairness criteria, the protocol overhead or the degradation degree of the flows [8,9]. These algorithms, however, do not account the condition of wireless channel that can affect the performance of the wireless system. In a network can be present situation in which it is not useful to give a particular amount of bandwidth if the channel is in a bad condition and the error rate is so high. In this case can be more useful to give the bandwidth to flow that can take advantage of a better state of the channel.

Different users may experience different link capacities due to different locations, and we believe that bandwidth should be allocated in an adaptive and link-state dependent way. To consider the heterogeneity of different applications and to have a consistent performance measure, we adopt utility functions in our proposed adaptive QoS model. In this paper, we propose an utility-oriented bandwidth allocation scheme and admission control policy, which account for the users' QoS requirements and actively adapts to the dynamics of the physical channel. There has been much work on wireless resource management, focusing on multiple access and channel allocation, however there is less research on adding an explicit adaptive mechanisms to bandwidth allocation schemes to deal with the variations of wireless channels. The rest of the paper is organized as follows. Section II discusses the user mobility effect and the wireless variations. In Section III the link model and the utility oriented adaptive QoS model are discussed. Section IV describes the simulation results and Section V concludes the paper.

## II. DEALING WITH USER MOBILITY AND LINK VARIATIONS

In order to offer an adaptive QoS or a "better than best-effort" service due to the inherent time varying environmental conditions evident in radio communications (e.g. fading), it is used an architecture capable to reserve bandwidth levels and to offer guaranteed services. This last one is the Integrated Services Network [2] with mobile host and Mobile Resource Reservation Protocol (MRSVP) [3] is used for exchanging state information of wireless networks. This protocol can offer soft QoS (adaptive QoS) for a class of services called Mobility Independent Predictive (MIP) and users belonging to this class request service guarantees, regarding delay in packet delivery and drop probability during hand-off events. According to adaptive multimedia wireless framework [4], MIP can reserve a bandwidth level that can change during call holding time. These behaviour can guarantee a more flexible resource management increasing the system utilization. The MRSVP protocol ensures the absence of flow dropping for MIP class when the users change their coverage areas by the passive reservation policy: an *active reservation* is made in the actual coverage access point (where the connection is born) and a certain amount of *passive bandwidth* (dependent on the allocation schemes used) is reserved in the remote access points, that will be visited by user during the connection. In this way, MIP users cannot find a new overloaded cell during a hand-off event and they can be served in adequate manner to continue their data sessions.

User mobility is also one of the reasons which cause channel quality degradations during a connection: we considered the multi-path fading phenomenon, as direct consequence of user mobility and time-varying impulse response of radio links; in particular our work takes in account the *slow-fading* effect, which takes place when the evolution of link changes can be considered to be slower than symbol transmission time. In this way, we give more effectiveness to used rate adaptation algorithm and reservation protocol, because the offered network service always guarantees the minimum delay requests made by users, by allocating more resources to face transmission errors due to absence of ideality in radio channels. To handle physical link variability, low level mechanisms, such as error correction coding and swapping transmission opportunities in packet scheduling, are usually used, but they become inadequate for slow link variations; we introduced a high-level bandwidth allocation scheme that adjust the average bandwidth share of each user as the link quality changes.

As we seen, mobility and fading can change system conditions, so it is necessary to use rate adaptations algorithms for varying bandwidth levels, according to channel conditions and host mobility. In this case, the used rate adaptation algorithm is based on an *utility function* associated to MIP class and it tries to maximize the *user profile satisfaction* modelled by these target functions [5].

## III. System Modeling

### A. Modeling the Time-varying Link

In our work we employed a Markov chain model to describe the behavior of a radio-link between users and access-points, as proposed in [6]. We needed to introduce the chain model to consider the absence of ideality in wireless communications and the fluctuations in the received signal level, due to the various propagation phenomena during a generic connection (shadowing, refraction, fading, etc.). As we will see, each chain state has an associated ratio, which represents the received percentage of corrupted bits. The model can only be used under the assumption of *slow fading*.

Let S = $\{s_0, s_1, \ldots, s_{K-1}\}$ denote a finite set of states and $\{S_n\}$, n=0,1,2,… be a constant Markov process, with the property of *stationary* transitions, then the transition probability is independent of the time index *n* and can be written as

$$t_{j,k} = P_r(S_{n+1} = s_k \mid S_n = s_j), \tag{1}$$

for all $n$ = 0,1,2,… and $j,k \in \{0,1,2,\ldots,K-1\}$; we can define a *KxK* state transition probability matrix **T**, with elements $t_{j,k}$. Moreover, with the stationary transition property, the probability of state *k* without any state information at other time indices can also be defined as $p_k = \Pr(S_n = s_k)$, where $k \in \{0,1,2,\ldots,K-1\}$, so a *Kx1* steady probability vector **p** can be defined with its element $p_k$. To complete the description of the chain model, we require additional information on the channel quality for each state, so we can define a *Kx1* crossover probability vector **e** with its elements $e_k$, $k \in \{0,1,2,\ldots,K-1\}$. Now the FSMC is completely defined by **T**, **p** and **e**.

Under the hypothesis of a received signal envelope Rayleigh distributed, we can derive a relationship between physical channel and its finite-state model, by partitioning the range of the received SNR into a finite number of intervals.

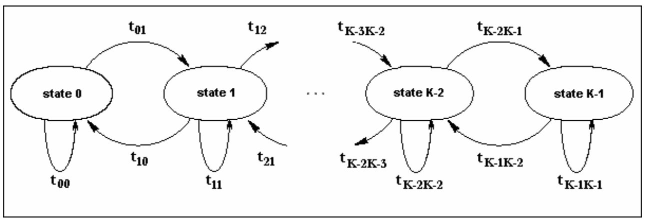


Fig. 1. A finite state Markov chain

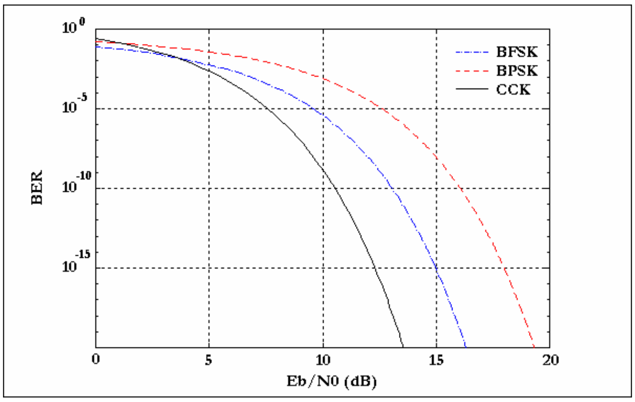


Fig. 2. SNR and BER for some digital modulation schemes

Let $0 = A_0 < A_1 < A_2 < \ldots < A_k = \infty$ be the thresholds of the received signal to noise ratio, then the Rayleigh fading channel is said to be in state $s_k$, $k$ = 0,1,2,…,K-1 if the received SNR is in the interval $[A_k, A_{k+1})$. Associated with each state there is a crossover probability $e_k$ and, given a specific digital modulation scheme, the average error probability is a function of the received signal to noise ratio (the value of $e_k$ is the average error probability on transmitting a bit when the received SNR falls in the k-th interval).

The elements of **p** and **e** can be written as follows:

$$p_k = \int_{A_k}^{A_{k+1}} \frac{1}{\rho} e^{-\frac{a}{\rho}} da, \tag{2}$$

$$e_k = \left[ \int_{A_k}^{A_{k+1}} \frac{1}{\rho} e^{-\frac{a}{\rho}} P_e(a) da \right] / p_k, \tag{3}$$

where $P_e(a)$ depends on the digital modulation scheme chosen. In our simulations we considered the CCK modulation (as in the standard IEEE802.11b) [7], and

$$P_{e(CCK)}(a) = 12Q\left(2\sqrt{a}\right) \tag{4}$$

Due to the non linearity between SNR and $e_k$, the SNR intervals may have to be non-uniform to be useful. Figure 2 illustrates the course of BER versus SNR for some kind of useful digital modulation schemes (*Binary Frequency Shift Keying, Binary Phase Shift Keying and Complementary Code Keying*).

The thresholds $A_k$, with $k = 0, 1, \ldots K-1$, can be calculated by choosing the desired values of cross-over probabilities, directly dependent from the degradation percentage of each state by an entropy function, and solving the previous expression for $e_k$ (in our work we proceeded in numerical way). Figure 3 shows the general partitioning method of SNR values.

The entire modelling technique is based on the knowledge of channel state information (CSI): we assumed that, given the channel capacity, we can obtain the related values of crossover probabilities by using an entropy function

In particular, when the CSI is available, the channel capacity is the average capacity over all the states:

$$C = \sum_{k=0}^{K-1} p_k [1 - h(e_k)] \tag{5}$$

where *h(.)* is the binary entropy function defined as:

$$h(e) = e\log\frac{1}{e} + (1-e)\log\frac{1}{1-e}. \qquad (6)$$

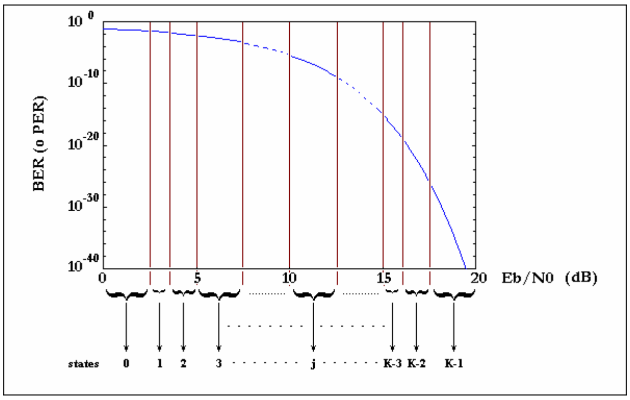

Fig. 3. Relation between SNR, BER and chain states

To calculate the transition probabilities $t_{j,k}$ we first assumed that the Rayleigh fading channel is slow enough that the received SNR remains at a certain level for the time duration of a channel symbol; furthermore, the channel states associated with consecutive symbols are assumed to be neighboring states. If $f_d$ is the maximum Doppler shift introduced by the user mobility and T the symbol transmission time, then we say that the slow-fading condition is verified if $f_d*T<<1$.

*B. Adaptive QoS Model and Bandwidth Allocation Scheme*

We used an *utility-oriented* algorithm for rate-adaptation and admission control, considering the time-varying nature of links, between hosts and access points [5]. In our case, we used monotonically non-decreasing utility functions, describing how the perceived utility changes with the amount of effective bandwidth received by the user. In our service model, each user *i* can signal its utility function $U_i(r)$ to the network, where *r* is the amount of effective bandwidth received by the user and the bandwidth allocated to a flow can take its discrete value from the set $B=\{l_1,l_2,\ldots,l_n\}$, where $l_i<l_{i+1}$ for $i=1, .., n-1$. It is assumed that the calls can belong to MIP class and all of them take (varying) bandwidth values from the same set *B*.

The network tries to dynamically allocate bandwidth such that each user's instant utility is maintained above the minimum level and, in the long run, the bandwidth is allocated fairly and utilized efficiently.

As described earlier, the communication link of each user can be modelled by a *k*-state Markov chain: we can indicate the average state-holding time of each state *m* with $t_m$ and the bandwidth degradation ratio of the state with $D_m$, where $0\leq D_m<1,\ \forall\ 1\leq m\leq k$. If, at a particular time instance, $r_i$ is the amount of bandwidth that the network is allocating to user *i*, we define the *received instant utility* as $u_i = U_i((1-D_{i,m})*r_i)$. One of the objectives of the bandwidth allocation scheme is to guarantee the minimum utility level for each user i; if we define *utility outage* as the event that user *i*'s instant utility level falls below the minimum, the scheme should guarantee that the probability of an utility outage is smaller than a certain threshold $p_{outage}$. In addition, the fairness criterion should also be based on utility: considering users i and j with average utility $u_{i,avg}$ and $u_{j,avg}$ respectively, we can define the *normalized gap* of the average utility received and the minimum level $u_{*,min}$ as: $G_i=(u_{i,avg}-u_{i,min})/u_{i,min}$, so we want all users to have the same normalized gap in the long run ($G_i\approx G_j,\ \forall i,j$).

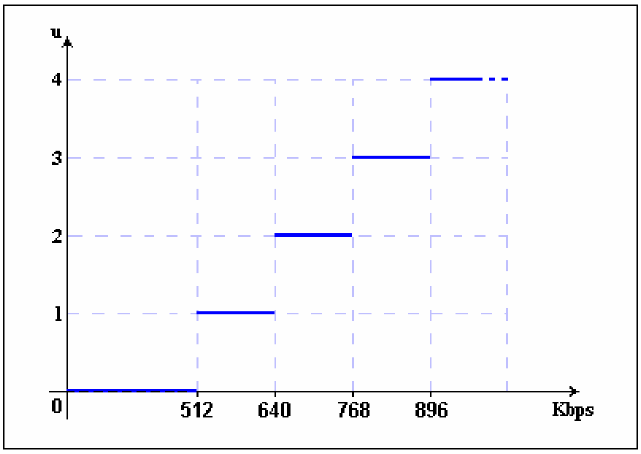

Fig. 4. An example of utility function

When a user's link *degrades*, it may surrender some bandwidth to another user, with a smaller normalized gap; when a link *upgrades* the user may receive some bandwidth from another one, with a larger normalized gap; in this way there is a net gain in the combined instant utility. If at a particular time user *i*'s link state changes to state *p*, the following steps are performed: 1) all users' average utility level and normalized gap are updated; 2) users are sorted in increasing order of normalized gap; 3) if the instant utility level of user *i* is below the minimum, some users' bandwidth will be reduced and reallocated to user *i* to meet its $u_{i,min}$; 4) if there is no step three, user *i* may give up part of its bandwidth to another user if the link degrades, whereas it may receive some bandwidth if the link upgrades. We call the user who gives up part of its bandwidth to others the *benefactor*, and the user who receives bandwidth from others the *beneficiary*. In the third step, to satisfy user i's $u_{i,min}$, the scheme searches for *benefactor(s)* starting from the user with the largest normalized gap. Suppose the user with the largest normalized gap is user j, whose link is currently in state q and it is above $u_{j,min}$. User j will yield

$$\min\left(\frac{r_{i,\min}}{1-D_{i,p}} - r_i, r_j - \frac{r_{j,\min}}{1-D_{j,q}}\right) \qquad (7)$$

amount of bandwidth to user *i*, where $r_i$ and $r_j$ are the bandwidth allocated to users *i* and *j*, respectively, before the link state transition. This procedure will be repeated until $u_{i,min}$ is reached or all the users have been checked.

When user i's link degrades, the scheme will search for an appropriate *beneficiary*, checking the users in increasing order of normalized gap; when the *beneficiary* is found, the scheme decides the amount of bandwidth to transfer between the users, trying to maximize the combined utility of them. This procedure is repeated until one *beneficiary* is found or all users with smaller normalized gap than user *i*'s have been checked. Similarly, when user *i*'s link upgrades, user *i* becomes the beneficiary and users with larger normalized gap are the candidates for *benefactor*. The scheme checks the candidates in decreasing order of normalized gap and, when the *benefactor* is found, the scheme decides the amount of bandwidth to exchange, maximizing the combined utility of the two users. Besides the link state changes, adjustments in bandwidth allocation are also needed when an user arrives (new user) or departs. If *r* is the amount of bandwidth which needs to be collected from current users because of an user arrival, user *j* with largest normalized gap $G_j$ is to give up

$$\min(\max(0, r_j - \frac{r_{j,\min}}{1-D_{j,q}}), r) \quad (8)$$

amount of bandwidth, where q is the current link state of user j. This procedure will be repeated until enough bandwidth has been collected or all the current users have been serched. If after searching all the current users, the collected bandwidth is still not enough, the scheme will start a second round of collection, again starting from the user with the largest normalized gap, but, this time, each chosen user will be dropped out from the network. Similarly, if there is surplus bandwidth, the users with the first k smallest normalized gap are chosen to receive the surplus bandwidth. Each user can increase its effective bandwidth up to the maximum effective bandwidth level.

To guarantee users' minimum utility level, an admission control policy should be enforced to limit the number of users in the system. Recalling that when an user's instant utility falls below its minimum utility level there is an utility *outage* for the user, the probability $p_0$ of such event at any time is:

$$p_0 = P_r\left\{\sum_{i=1}^{n} \frac{r_{i,\min}}{1-D_{i,m_i}} > R\right\}, \quad (9)$$

where $m_i$ is user *i*'s link state at the time istance, $p_{mi}$ is the probability of the user *i*'s link to being in state m at a particular time, n is the total number of users including the new one and *R* represents the bandwidth associated to the wireless cell *c*. Modelling the wireless channel through a FSMC, it is possible to know the value of $p_0$ in the worst case, accounting the channel state conditions in the following way:

$$p_0 = \sum_{A} \prod_{1\le i\le n} p_{m_i}, \quad A = \{m_1, m_2, ..., m_n \mid 1 \le m_1, ..., m_n \le k, \sum \frac{r_{l,1}}{1-D_{l,m_l}} > R\}. \quad (10)$$

The admission control algorithm works differently for two classes of service (MIP, MDP). For MIP class, the flow is admitted if:

$$\sum_{c=1}^{C} p_{0,c} \le C \cdot p_{outage}, \quad (11)$$

where C = number of cells that mobile host will visit and $p_{outage}$ is the outage probability of the wireless system (for MDP class, the condition must be verified only for the current cell). So, when a new user arrives, the scheme calculates $p_{0,c}$ as described and if $p_{0,c} \le p_{outage}$ for each cell, the new user is admitted, otherwise it is rejected. If a user *j* is admitted, it is initially allocated $r_{j,min}/(1-D_{j,q})$, where q is user *j*'s current link state. The assigned amount of bandwidth to *j* is contributed by the users currently in the network following the algorithm we described previously.

## IV. Simulations

Our simulated net consists of 5 wireless cell, each one covered by an access point (as illustrated in figure 5) with bandwidth capacity of 5.5Mbps; the access points are wired connected, by a switching subnet, to the net-sender.

In our model, each mobile host moves ahead in circular way: a user that is receiving data in cell 5 will visit cell 1, after a hand-off. Each wireless link is described by a 4-states Markov chain, with the following parameters:

Tab..1 Values for the Markov chain model

| | $p_i$ | $e_i$ | $D_i$ (%) | $t_{mi}$ (s) |
|---|---|---|---|---|
| 0 | 0.30233 | 0.150588 | 41.8 | 0.1 |
| 1 | 0.095 | 0.0670038 | 24.58 | 0.1 |
| 2 | 0.25267 | 0.016459 | 9.5 | 0.1 |
| 3 | 0.35 | 5.92112e-5 | 0 | 0.1 |

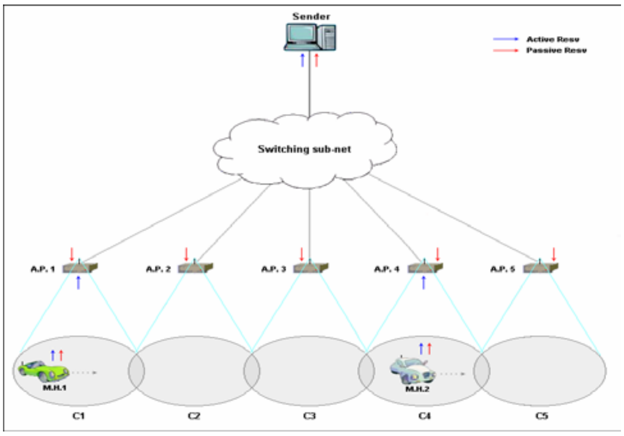


Fig. 5. The simulated net

The protocol used in the simulations has been the MRSVP [3] with MIP and MDP services. The MIP services have the capability to make advance reservation on the potentially visited cells offering a adaptive QoS with the host mobility. The MDP services can reserve the resources only on the current cell and for this reason they are not able to guarantee an adaptive QoS with host mobility. The MIP services are evaluated for different outage probabilities fixed on the CAC algorithm.

The set of possible discrete bandwidth levels (Kbps) is: B = {512, 640, 768, 896} and the utility function is the same of figure 4, so the set of instant utility values is: U = {1,2,3,4} for all users. In our simulations the traffic load is composed by MIP and MDP flows, as provided in ISPNs: in particular, there are 80% MIP and 20% MDP flows. The bandwidth is managed by the policies illustrated in Section III and the outage threshold is the same for both flow classes (conjunctive bandwidth management). The mobile host can move with average speed selected uniformly in range [5,75] Km/h. The following curves illustrates the performances of the utility-oriented algorithm for different values of outage threshold and mobile host speed.

From figure 6 it can be observed that the allocated bandwidth for MIP users is near the maximum level for every host's speed and decreases by increasing the outage threshold: the admission control becomes less selective if the $p_{outage}$ value is increased, so more MIP users can enter the network; in this way, the available bandwidth is shared among a higher number of concurrent flows, which receive a lower amount of resources.

For the same reasons, the perceived utility from MIP users (figure 7) assumes different values, depending on the fixed threshold; higher $p_{outage}$ values imply lower perceived utility values. In figure 8 we can see that the system utilization does not exceed the 85% percentage and decreases for higher speed or higher threshold values. As the user's speed increases, the physical radio link changes its state with higher frequency, so more bandwidth reallocation are made by the system and this implies a resource wastage; in addition, if a high threshold value (like 0.4) is fixed, more users can access the system, which tries to avoid outage events more frequently; this is another reason of bandwidth wastage, which causes an under-utilization of the network. The absence of an high system utilization values derives from the presence of high percentage of MIP traffic (80%): there is a lot of bandwidth wastage, due to the passive reservations made by system (MIP flows reserve the maximum bandwidth level in their remote cells). Figure 9 shows the average number of admitted MIP flows and, as discussed above, it can be observed that there is a visible increase for higher values of outage threshold: the system admits a larger number of users, but gives smaller guarantees about the outage events.

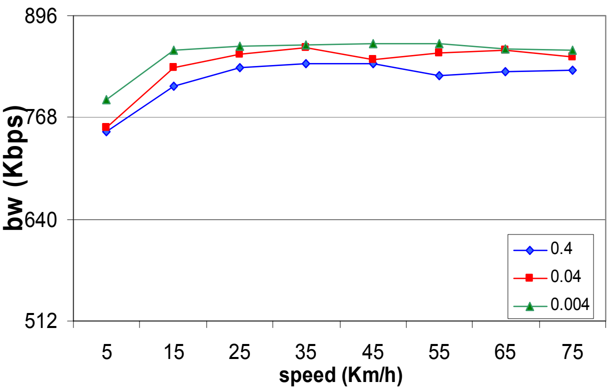


Fig. 6. Allocated bandwidth to MIP services for different outage probability $p_0$ and speed values.

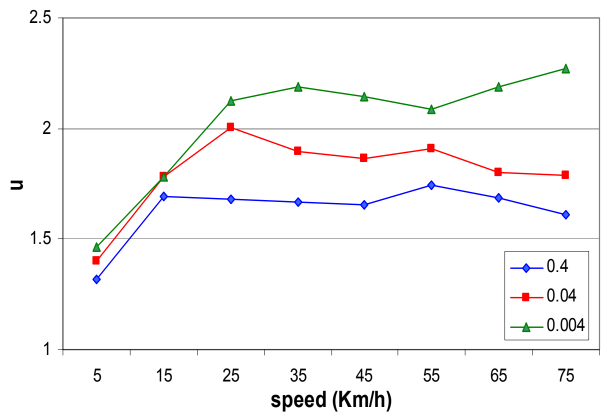


Fig. 7. MIP received utility for different outage probability $p_0$ and speed values

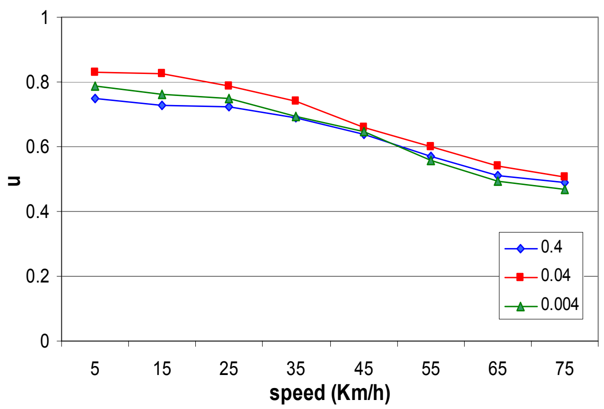


Fig. 8. System utilization (*100) for MIP services for different outage probability $p_0$ and speed values

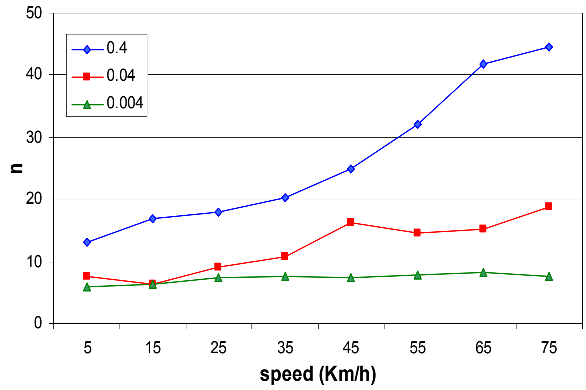


Fig. 9. Admitted MIP flows for different outage probability $p_0$ and speed values

## V. CONCLUSIONS

In this paper we analyzed the performances of a proposed utility-oriented algorithm and we also seen that there is need to consider the physical link variability, in order to give more effectiveness to bandwidth allocation schemes and to take in account the absence of ideality during radio connections. From simulation results we observed that the channel degradation becomes more evident for high speed values and the hand-off number increases, but the pre-reservation of MIP classes guarantees a full compliance to QoS parameters (outage probability and maximized user utility function) for low values of outage threshold, so the mobility effects are minimized.

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