Characterization of Adaptive Modulators in Fixed Wireless ATM Networks

Abbas Mohammadi and Surinder Kumar

Abstract: **The various challenges to realize a fixed wireless ATM network are discussed and some solutions for these challenges are presented. In this paper, the capacity allocation in wireless ATM, the wireless link impact on ATM traffic, and the optimum utilization of the wireless network resources for a line of sight (LOS) wireless ATM link are studied. An adaptive MQAM modulator is introduced to provide a suitable solution to these issues. The modulator level is adjusted using a unique QoS metric in a wireless network. The metric, termed modified effective bandwidth, takes into account the bandwidth demand, QoS requirements, and outage conditions of the wireless ATM link. A performance study using VBR MPEG-1 video traffic in a fixed wireless channel (Ricean channel) demonstrates the advantages of the proposed system.**

Index Terms: **Adaptive modulator, ATM networks, fixed wireless, MQAM.**

I. INTRODUCTION

The introduction of the asynchronous transfer mode(ATM) networking technique has been an important contribution factor to realize wireless broadband communications. ATM is an efficient networking technique that is designed to transmit different classes of traffic over the same network. It can also be used as a platform for broadband wireless communications. An ATM network has the feature of statistical multiplexing which maximizes the use of the available wireless network capacity when traffic originates from multiple sources [1]. Moreover, the ATM technique provides the capability for delivering bandwidth-on-demand. This area in telecommunications has created a number of new research challenges which are summarized as follows:

- How much capacity is required for a broadband traffic source and how it can be measured.
- What is the impact of a fixed wireless link on ATM traffic and how it can be modelled.
- How can we define a metric to characterize the ATM transmission over a fixed wireless link and how it can be used in real time?
- A design to optimize the wireless network utilization and how it can be implemented.

The first challenge is related to characterization of the broadband traffic sources. The communications networks are becoming more dynamic and complex as new services such as Internet, multimedia calls, interactive T.V., and video conferencing are being introduced. These services not only require various bandwidth but also demand various quality of service (QoS) requirements.

The next challenge is arised due to transmission of broadband traffic over wireless channel. In a broadband wireless system, two different mechanisms cause QoS degradations. While the buffer congestion results in cell loss ratio at nodes, the physical layer introduces bit errors which increases the overall cell loss ratio. Moreover, the available spectrum in the wireless channel is limited and this limitation has to be taken into account in wireless system design. In addition, the estimation of the radio link capacity variation due to multipath fading is another issue that has to be addressed.

An important challenge is to derive an end-to-end performance bound for the wireless ATM network. An end-to-end performance study in the case of a wireless broadband network should result a bound that always guarantees operation with desired QoS measures. Estimation of a bound that optimizes the network utilization is a very interesting challenge [2]. The issue that follows is how to design a system to optimize the utilization of the wireless network resources. While an adaptive system design can be a solution, the characterization of an adaptation metric is an essential task.

These research challenges are examined in this paper. The effective bandwidth as a metric of the quality of service has been used in the past to provide an unique metric to deal with the bandwidth demand and QoS requirements [3], [4]. Using this metric and a capacity reduction factor to describe the impact of wireless channel on ATM transmission not only addresses the cell loss ratio due to burst error but also estimates the capacity variation due to multipath fading. A new concept termed as modified effective bandwidth is introduced to characterize the transmission of ATM cells over wireless channel. While this metric characterizes the performance of network nodes (e.g., bandwidth allocation, buffer congestion, etc.) it also considers the impact of the wireless channel. In addition, an adaptive MQAM transmitter, adapted by the modified effective bandwidth, is also introduced as an efficient method to realize a fixed wireless ATM network.

The paper is organized as follows: First, the required bandwidth of the broadband traffic is studied using a comparison between measured results of empirical traffic traces and a statistical model. Then, the impact of burst error in wireless link and capacity variation due to multipath fading are examined. This is followed by extraction of the modified effective bandwidth function. Finally, a transmitter based upon MQAM modulator is introduced to optimize the utilization of wireless network resources.

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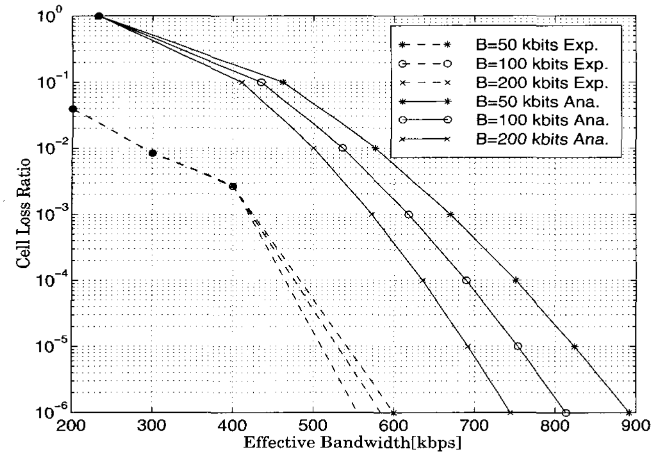

Fig. 1. Experimental P_{CLR} versus BW_{eff} using buffer sizes as a parameter for *StarWars* movie.

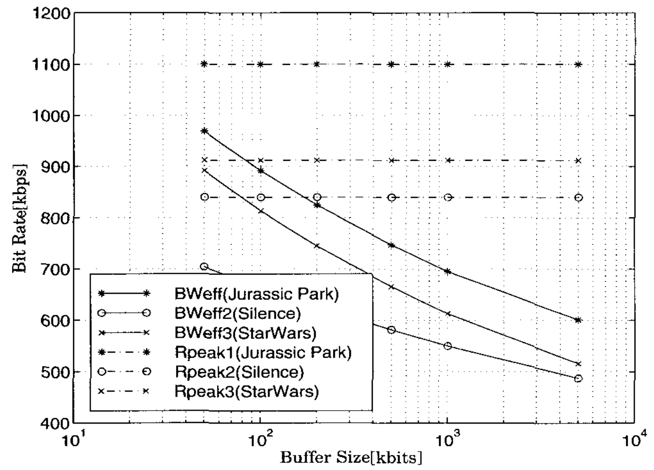

Fig. 2. Effective bandwidth and peak rates of different video traces with $P_{\mathrm{CLR}} = 10^{-6}$.

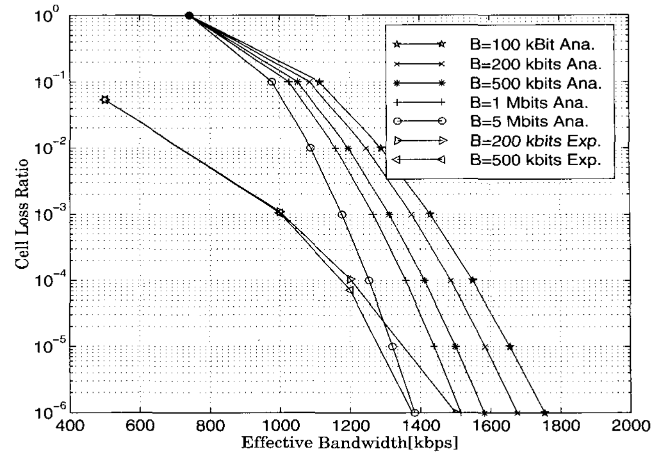

Fig. 3. Experimental P_{CLR} versus BW_{eff} using buffer sizes as a parameter for aggregates video.

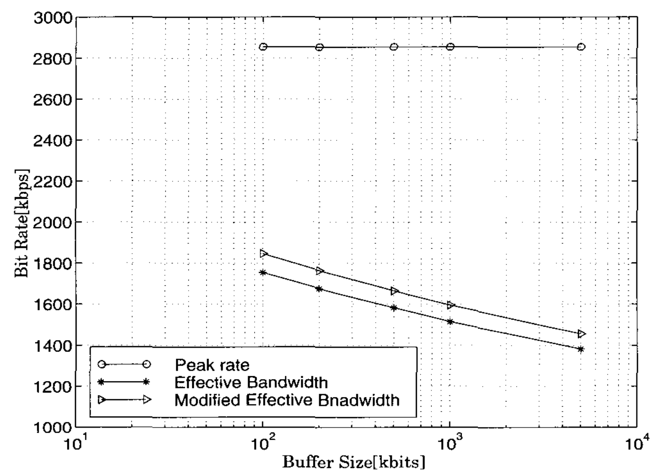

Fig. 4. The peak bandwidth, effective bandwidth, and modified effective bandwidth for aggregate video traffic. The cell loss ratio is 10^{-6} in a Ricean channel.

II. EFFECTIVE BANDWIDTH OF BURSTY SOURCES

The required bandwidth of the broadband traffic can be statistically characterized by an effective bandwidth. The effective bandwidth of a time varying traffic source represents the minimum required bandwidth that guarantees its QoS requirements. Assigning an effective bandwidth function to each traffic source, which depends not only on its mean bandwidth but also on its burstiness, gives a suitable tool to estimate the required bandwidth of each traffic source. In a series of papers, researchers from Bellcore have reported the measurement results of real traffic sources [4]–[6]. Their results show that the different bursty traffic sources have a self-similar or long-range dependent behavior. A statistical model based upon self-similar or long-range dependency(LRD) model has been found that provides a suitable upper bound to estimate the required bandwidth of the broadband traffic [7], [8]. The model results a closed form relation as follows [7]:

$$BW_{\mathrm{eff}} = R_{\mathrm{mean}} + \left(K(H)\sqrt{-2\ln(P_{\mathrm{CLR}})}\right)^{1/H} \times a^{1/(2H)}\Pi^{-(1-H)/H} R_{\mathrm{mean}}^{1/(2H)}, \quad (1)$$

where $K(H) = H^H(1-H)^{1-H}$. P_{CLR} is the ATM cell loss ratio (the ratio of the discarded cells to the transmitted cells), a is the variance parameter and is defined as variance over mean (in bit-sec), H is Hurst parameter of the stream (a dimensionless measure of long-range dependency with value between 0.5 and 1), Π is buffer size in bits, and R_{mean} is mean rate in bps. The accuracy of this upper bound was compared with the actual required bandwidth of the video traffic sources. The required bandwidth of the MPEG-1 video traces [9] were measured by simulation of an ATM multiplexer. The accuracy of this model is evident from Fig. 1 where the actual required bandwidth of *StarWars* movie is upper bounded with its effective bandwidth using a buffer size as a parameter. The advantage of using the effective bandwidth instead of the peak rate bandwidth [10], [11] for different videotraces, namely *Jurassic Park*, *Silence of the Lambs*, and *StarWars*, is quite clear from Fig. 2 for a cell loss ratio 10^{-6}. As presented in these figures, depending on buffer sizes, a bandwidth saving about 20 to 40 percent for video transmission may be achieved. The saving is gained for a cell loss ratio 10^{-6} at the expense of the cell delay increase.

Table 1. Traffic characteristics of various video traffic sources (Mean bit rate (Mbps) and variance parameter (bit-second)).

	Mean	Var. Cof.	Hurst
Jurassic Park	0.327	4.93×10^4	0.85
Silence of Lambs	0.183	6.48×10^4	0.90
StarWars	0.233	7.25×10^4	0.85
Terminator II	0.273	2.73×10^4	0.89
Mr. Bean	0.441	1.09×10^5	0.85
Soccer	0.678	9.02×10^4	0.91

The saving percentage is a parameter of the buffer size. Fig. 3 compares the actual required bandwidth of aggregate of three MPEG-1 coded movies (using Table 1) with its effective bandwidth. As presented in Figs. 2 and 3, using the effective bandwidth also shows a statistical multiplexing gain for aggregate video traffic. For instance, while the effective bandwidth of the videotraces are 760, 590, and 680 kbps for a buffer size of 350 kbits, their aggregate traffic requires only 1500 kbps bandwidth using 1Mbits buffer size. This shows a statistical multiplexing gain of about 1.35. The peak rate and effective bandwidth is compared for aggregate video traffic in Fig. 4. As may be seen, a typical peak rate allocation requires about 2.5 to 3 Mbps capacity, while the effective bandwidth reduces it to around 1.5 Mbps.

These results show that a high bandwidth savings can be achieved using the effective bandwidth metric. It should be pointed out that this metric provides an accurate as well as a simple solution to a very complicated bandwidth estimation problem.

As can be seen, this statistical model also provides a close upper bound compared to actual required bandwidth of the broadband traffic. The above equation has to be further modified to take into account the delay limitations of ATM sources. If the maximum tolerable delay is $D_{\max}$, the relation between maximum delay, the required bandwidth BW, and the buffer size, Π may be written as

$$\frac{\Pi}{BW_{\text{eff}}} \leq D_{\max}. \quad (2)$$

The inequality may be substituted with equality in (2) when an effective bandwidth is assigned. Using (2), (1) can be modified as

$$BW_{\text{eff}} = R_{\text{mean}} + \left(K(H)\sqrt{-2\ln(P_{\text{CLR}})}\right)^{1/H} \times \alpha^{1/(2H)}(BW_{\text{eff}} D_{\max})^{-(1-H)/H} R_{\text{mean}}^{1/(2H)}. \quad (3)$$

This equation can be rearranged to collect the effective bandwidth terms at the left hand side as

$$BW_{\text{eff}}^{1/H}\left(1 - \frac{R_{\text{mean}}}{BW_{\text{eff}}}\right) = \left(K(H)\sqrt{-2\ln(P_{\text{CLR}})}\right)^{1/H} \times \alpha^{1/(2H)}(D_{\max})^{-(1-H)/H} R_{\text{mean}}^{1/(2H)}. \quad (4)$$

This is a nonlinear equation that relates the effective bandwidth to the required cell loss ratio, P_{CLR}, and maximum delay, $D_{\max}$. This equation has to be solved numerically to obtain the effective bandwidth value for a given cell loss ratio and maximum delay.

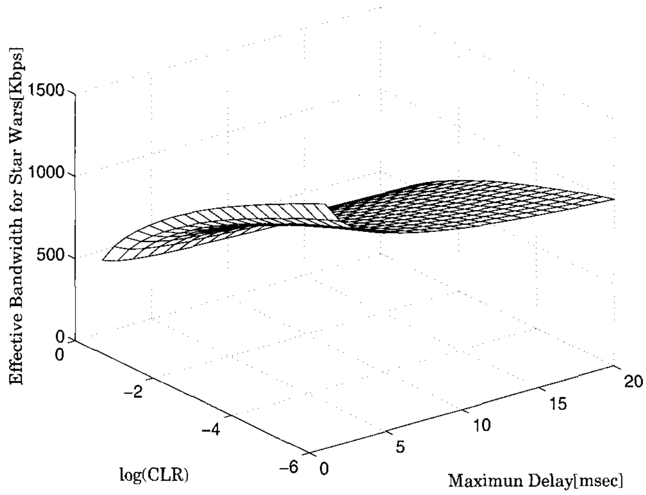

Fig. 5. Effective bandwidth of *StarWars* movie as a function of cell loss ratio and maximum delay.

The *StarWars* movie again is used for this consideration. Using Table 1, the traffic parameters for this movie are $R_{\text{mean}} = 232.83$ kbps, $a = 7.25 \times 10^4$ bit-sec, and $H = 0.8458$, the effective bandwidth as a function of P_{CLR} and $D_{\max}$ was computed using (4) and results are presented in Fig. 5. The figure shows that the required effective bandwidth is a function of cell loss requirement and delay constraint. This suggests that if optimum transmission of multimedia traffic is desirable, a flexible transmitter design is essential.

III. IMPACT OF A FIXED WIRELESS LINK ON ATM TRAFFIC

A. *Cell Loss Ratio Due to Channel Performance*

An ATM network has been originally proposed to use a high performance physical layer. A radio link has lower performance that is required in an wireless ATM link design. In this section, the impact of wireless channel on ATM traffic is examined. The cell loss ratio(CLR) is defined as being the ratio of the discarded cells to the transmitted cells. In the following analysis, only the cell loss ratio resulting from the corruption of the header in the ATM cells is considered.

A.1 Quality of Service for the Random Error Channel

When bit errors occur independent and identically distributed, the error distribution is binomial. We assume that the header error correction (HEC) can only correct a single bit error in the 40 bit header and neglect the dual mode operation for HEC. Using binomial distribution, the CLR is obtained from

$$p_{\text{CLR}}^r = \sum_{n=2}^{40} \binom{40}{n} p_b^n (1-p_b)^{40-n}. \quad (5)$$

An approximation to (5) can be obtained [12]:

$$p_{\text{CLR}}^r \simeq 780 \times p_b^2, \quad (6)$$

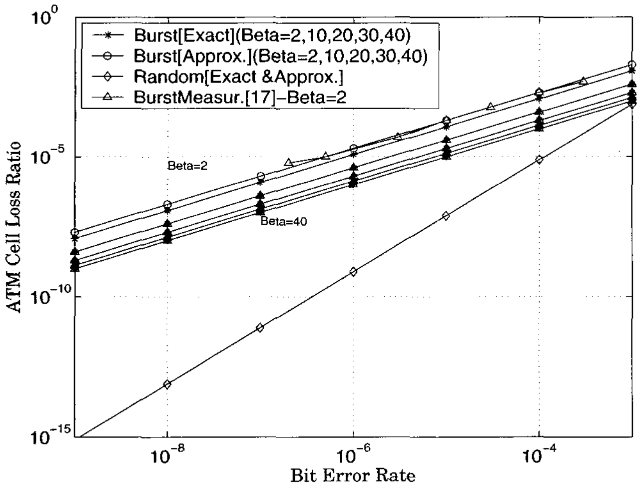

Fig. 6. CLR versus BER for random and burst channels.

where p_b is the bit error rate and p^r_{CLR} is the cell loss ratio in the random error channel. The approximation is more accurate for small value of p_b.

A.2 Quality of Service for the Burst Error Channel

The modeling of the error bursts at the output of a wireless receiver is an active research topic. Burst errors generally increase the probability of discarded cells. Here, a simple approximation, that mainly discusses the order of magnitude of the burst errors, is presented. Assuming that errors in burst are Poisson distributed, a suitable probability model in this case is the Newman-A contagious model [13]. In this model, the probability that k bit errors occur in an interval of l bit, when the mean error burst length is β, is given by

$$P(X=k)=\frac{\beta^k}{k!}e^{-lp_b/\beta}\sum_{n=0}^{\infty}\left(\frac{lp_b}{\beta}e^{-\beta}\right)^n\frac{n^k}{n!}, \quad (7)$$

where the probability of bit error is p_b. We model the cell loss ratio as the probability that more than one error occurs in the l bits of the header, neglecting the fact that ATM actually uses a dual mode operation for HEC. An approximation is presented for CLR in burst channel as follows [12]:

$$p^b_{\mathrm{CLR}}=1-e^{-40p_b/\beta}\left[1+\frac{40p_b}{\beta}(1+\beta)e^{-\beta}\right]. \quad (8)$$

There is a very good agreement between these analytical results and previously published measurements [14]. In Fig. 6, the relation between bit error rate and CLR for the random and bursty channel are plotted using burst length as a parameter.

B. Capacity Reduction due to Channel Fading

In an ATM network, a virtual path (VP) is an information transport that makes a logical direct link between two nodes. Each virtual path has a bandwidth, in other words, *capacity*, which defines the upper limit for the total virtual channel bandwidth that are multiplexed using cell multiplexing [15]. The effective bandwidth of a virtual path represents the minimum required capacity that guarantees its QoS requirements.

The capacity of a high speed link, C, has the following relation with the effective bandwidth of individual virtual paths.

$$\sum_{i=1}^{N} BW_{\mathrm{eff}_i}\le C, \quad (9)$$

where N is the number of VPs and BW_{eff_i} is the effective bandwidth of ith VP. The available capacity in a wireless ATM link is a function of channel performance as well. The capacity reduction due to fading is defined as

$$\xi^c=\frac{\int_\gamma C_w p(\gamma)d\gamma}{C_w}, \quad (10)$$

where ξ^c is called capacity reduction factor, γ is the carrier to noise ratio (CNR) and $p(\gamma)$ is the probability density function of the received CNR, and C_w is the capacity in an additive white guassian noise (AWGN) channel. For line of sight (LOS) radios, the fading distribution is Ricean [16]. For a Ricean channel, the probability density function of the received signal to noise ratio is obtained as [17]

$$p(\gamma)=\frac{1+K}{\Gamma}\exp\left(-K-\frac{\gamma}{\Gamma}(1+K)\right)I_o\left(2\sqrt{\frac{\gamma}{\Gamma}(K^2+K)}\right), \quad (11)$$

where Γ is the average power of γ and K is Rice parameter ($K\to 0$ for a weak direct wave and $K\to\infty$ for a strong direct wave), and I_o is the modified Bessel function of the order zero. According to (9) and (10), for a fading channel, the available capacity in an ATM link is limited to

$$\sum_{i=1}^{N} BW_{\mathrm{eff}_i}\le \xi^c C. \quad (12)$$

This relation suggests that a dynamic bandwidth demand could be responded to by a variable capacity transmitter.

IV. ADAPTIVE MQAM MODULATOR FOR WIRELESS ATM

A. MQAM in AWGN Channel

The spectral efficiency of the MQAM ($M=2^k$, where k is constellation size) modulator using a raised cosine filter with roll-off factor α is given by [18],

$$\eta=\frac{C}{W}=\frac{\log_2 M}{1+\alpha}, \quad (13)$$

where M is the modulation level, C is the channel capacity, and W is the physical channel bandwidth. As shown in (29) and (32) of [18], (7) and (8) of [19] and through out paper [20], the same steps to estimate the average capacity over fading channels can be used to estimate the average spectral efficiency over fading channels. Thus, using (9) the number of possible VPs for an AWGN channel is given by

$$\sum_{i=1}^{N} BW_{\mathrm{eff}_i}\le \frac{W\log_2 M}{1+\alpha}. \quad (14)$$

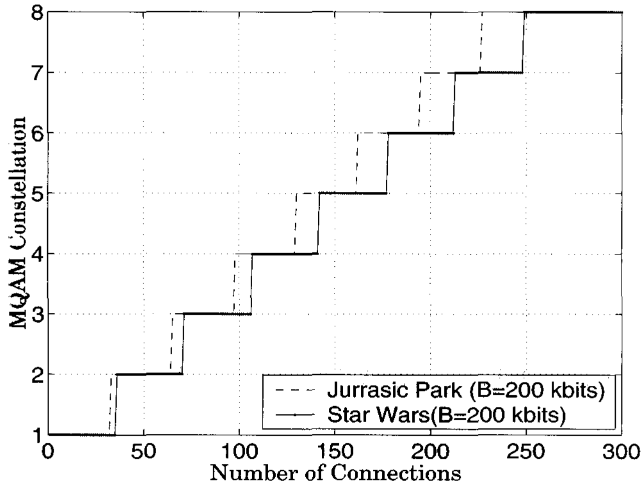

Fig. 7. The constellation size variation with the number of connections.

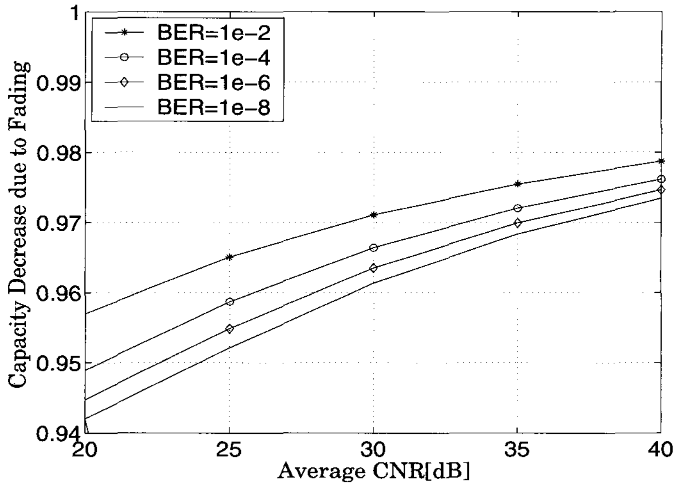

Fig. 8. Capacity reducton factor in a burst error channel ($\beta = 2$)

This shows that the modulation level can be selected using the following criteria:

$$\log_2 M \geq \frac{(1+\alpha)\sum_{i=1}^{N} BW_{\mathrm{eff}_i}}{W}. \quad (15)$$

The relation shows that MQAM modulator can respond to a dynamic bandwidth demand with varying the level of the modulation. The structure of a varying level QAM modulator has recently been introduced based on laboratory test results [21]. This structure utilizes an adaptive modulator in the time division duplexing (TDD), where the modem mode switching criterion is based on signal to noise ratio. A suitable constellation size is assigned to the modulator according to the VPs effective bandwidth calculation. As a typical example, MQAM was studied in an AWGN channel using a raised cosine filter with a roll-off factor $\alpha = 0.5$ with a 40 MHz channel bandwidth for a number of similar videotraces, namely, *Jurassic Park* with $BW_{\mathrm{eff}} = 824.23$ kbps, and *Silence of the Lambs* with $BW_{\mathrm{eff}} = 626.96$ kbps. A buffer size of 200 kbits and a cell loss ratio 10^{-6} were considered. The constellation size selection based on the number of connections obtained for this case is shown in Fig. 7.

B. MQAM in Multipath Fading Channel

A capacity reduction factor can be derived using (10) for MQAM modulators. For simplicity, a bit error rate upper bound was used for the study of an MQAM modulator [22].

$$p_b \simeq 0.2\exp\left(-\frac{3\gamma}{2(M-1)}\right). \quad (16)$$

The approximate bit error rate expression upper bounds the exact expression for $M \geqslant 4$ and for BER$\leqslant 10^{-2}$, which is the range of interest [23]. Using (16), the modulation level is obtained:

$$M \simeq 1 - \frac{3\gamma}{2\ln(5p_b)}. \quad (17)$$

Using (10), the capacity reduction factor in the multipath channel for MQAM modulator can be obtained as follows [19], [20]:

$$\xi^{c}_{M\mathrm{QAM}} = \frac{\int_\gamma \log_2(1 - 3\gamma[2\ln(5p_b)]^{-1})p(\gamma)d\gamma}{\log_2(1 - 3\gamma[2\ln(5p_b)]^{-1})}. \quad (18)$$

This factor is illustrated in Fig. 8 for Ricean channel and different BER requirements. Using this factor for bandwidth allocation, (14) can be modified as

$$\sum_{i=1}^{M} BW_{\mathrm{eff}_i} \leq \frac{\xi^{c}_{M\mathrm{QAM}} W \log_2 M}{1+\alpha}. \quad (19)$$

This shows that the constellation size selection can use the following criteria:

$$\log_2 M \geq \frac{(1+\alpha)\sum_{i=1}^{M} BW_{\mathrm{eff}_i}}{W\xi^{c}_{M\mathrm{QAM}}}. \quad (20)$$

C. MQAM for ATM Cell Transmission in Multipath Fading

Using (6), an approximate relation between BER and CLR in a channel with i.i.d. errors is expressed as follows:

$$p_b^2 \simeq \frac{p^r_{\mathrm{CLR}}}{780}, \quad (21)$$

where p^r_{CLR} is the cell loss ratio in channel with independent and with identically distribuated errors. Using (21) in (18), the capacity reduction factor for a random error channel is obtained as

$$\xi^{cr}_{M\mathrm{QAM}} = \frac{\int_\gamma \log_2(1 - 3\gamma[\ln(p^r_{\mathrm{CLR}}/31.2)]^{-1})p(\gamma)d\gamma}{\log_2(1 - 3\gamma[\ln(p^r_{\mathrm{CLR}}/31.2)]^{-1})}, \quad (22)$$

where $\xi^{cr}_{M\mathrm{QAM}}$ is the capacity reduction factor for the MQAM in a random channel. A similar relation is extracted for a burst error channel. Using (8), the bit error rate and cell loss ratio relation for small value of p_b in a burst channel can be approximated as

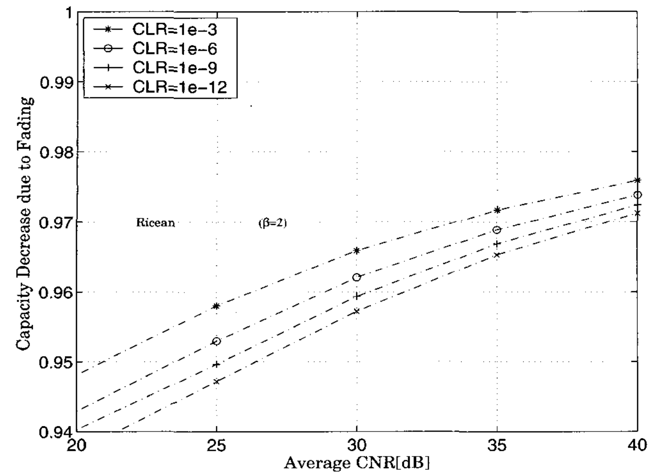

Fig. 9. Capacity reduction due to Ricean fading in MQAM (K=5 and $\beta = 2$ for Rice channel).

$$p_b \simeq \frac{\beta p^b_{\mathrm{CLR}}}{40}, \tag{23}$$

where β is the burst length and p^b_{CLR} is the cell loss ratio due to burst channel. The approximation is indeed an upper bound and is more accurate when β is big. Thus, the capacity reduction factor in burst channel is obtained as

$$\xi^{cb}_{M\mathrm{QAM}} = \frac{\int_\gamma \log_2(1 - 3\gamma[\ln(\beta p^b_{\mathrm{CLR}}/40)]^{-1})p(\gamma)d\gamma}{\log_2(1 - 3\gamma[\ln(\beta p^b_{\mathrm{CLR}}/40)]^{-1})}, \tag{24}$$

where $\xi^{cb}_{M\mathrm{QAM}}$ is the capacity reduction factor for the MQAM in a burst channel. The capacity reduction factor due to the cell loss ratio in a Ricean burst error channel with $\beta = 2$ is presented in Fig. 9.

D. Modified Effective Bandwidth for MQAM

A general relation between the transmission capacity and the number of the permitted calls in a wireless ATM link can be written as follows [24]:

$$\frac{1}{\xi^c_{M\mathrm{QAM}}(p^C_{\mathrm{CLR}})} \sum_{i=1}^{N} BW_{\mathrm{eff}_i}(p^B_{\mathrm{CLR}}) \leq C, \tag{25}$$

where p^C_{CLR} is the cell loss ratio due to channel, and p^B_{CLR} is the cell loss ratio due to cell blocking. The modified effective bandwidth metric, can be defined as

$$\sum_{i=1}^{N} BW_{\mathrm{meff}_i}(p^B_{\mathrm{CLR}}, p^C_{\mathrm{CLR}}) \leq C, \tag{26}$$

where

$$BW_{\mathrm{meff}_i}(p^B_{\mathrm{CLR}}, p^C_{\mathrm{CLR}}) = \frac{1}{\xi^c_{M\mathrm{QAM}}(p^C_{\mathrm{CLR}})} \sum_{i=1}^{N} BW_{\mathrm{eff}_i}(P^B_{\mathrm{CLR}}), \tag{27}$$

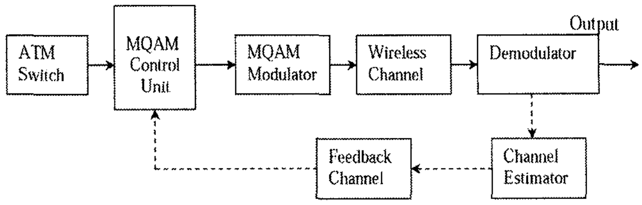

Fig. 10. A model for a fixed wireless ATM system.

is the modified effective bandwidth of each traffic connection. Using (20), the modulation level selection must be controlled in MQAM as

$$\log_2 M \geq \frac{(1+\alpha)\sum_{i=1}^{N} BW_{\mathrm{meff}_i}(p^B_{\mathrm{CLR}}, p^C_{\mathrm{CLR}})}{W}, \tag{28}$$

where BW_{meff_i} is the modified effective bandwidth of VP_i.

E. Adaptive MQAM Architecture

Based on the above theoretical results, an architecture for a fixed wireless ATM system using an MQAM modulator is proposed in Fig. 10. The signaling and the impact of time delay on the loop performance are treated in some detail in [18]. The function of the adaptive MQAM control unit is to select an optimum modulation level. The adaptation is based on an ATM call admission and wireless channel condition. The control unit for an adaptive MQAM control unit is presented in Fig. 11. The operation of control unit is described as follows.

According to Fig. 11, the ATM connections introduce their traffic and QoS parameters (e.g., tolerable cell loss ratio P_{CLR} and maximum delay $D_{\max}$) to the connection gate control block. According to their VP addresses, the connections are directed to different VPs. Then, the traffic characteristics of these VPs are recalculated to include the characteristics of the new connections. The buffer sizes are selected by the buffer size manager according to the delay constraints of each VP using (2). The effective bandwidth is calculated as a function of mean rate, cell loss ratio, cell delay, variance parameter, and Hurst parameter using (4). This is followed by a modified effective bandwidth estimation of the individual VPs. To do this, the capacity reduction factor, $\xi^c_{M\mathrm{QAM}}$, is computed according to (18).

The total value of the modified effective bandwidth is computed according to the new values of the modified effective bandwidth of individual VP_i, respectively. The modulator capacity is checked with the instantaneous bandwidth demand, and the modulation level is controlled according to the instant bandwidth demand. A constant power MQAM architecture has been assumed [18]. Using the constant power across modulation changes, a connection will not be accepted if the increasing the modulation level exceeds the acceptable cell loss ratio declared by the connection.

The outage estimator examines the outage percentage according to the new modulation level. The outage estimation is to be computed using a link design program which is initialized according to the specific radio link [12]. The outage is estimated

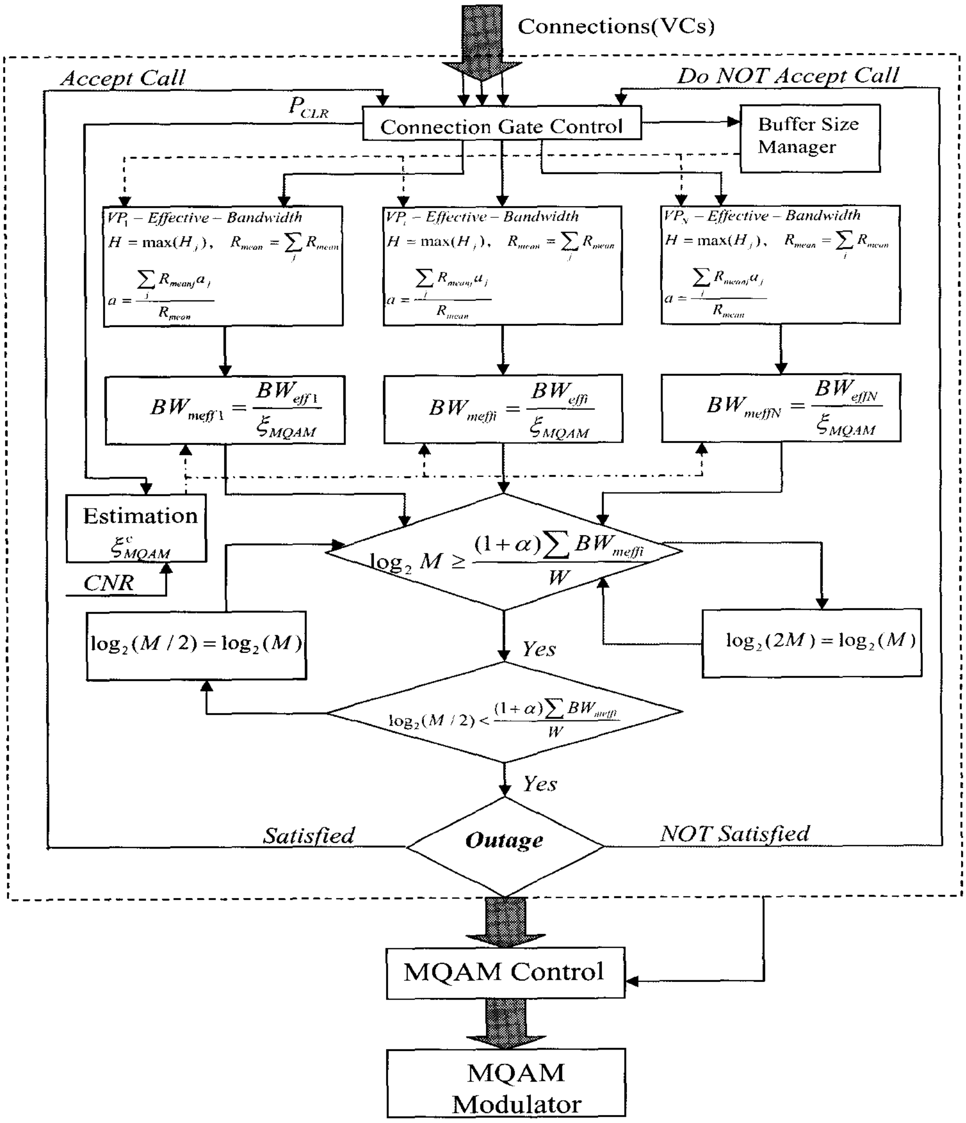

Fig. 11. The MQAM selection control.

to determine the system availability for a specific (20 dB) fade margin based on Barnett-Vignant reliability equations [25]. The k ($M = 2^k$) is increased so long as the desired system outage achieved. A positive acknowledgement from the outage estimator, implies that the gate control will permit the new connection to use the VP_i and radio link.

V. PERFORMANCE STUDY OF THE ADAPTIVE MQAM TRANSMITTER

A simulation study was conducted to evaluate the performance of the adaptive MQAM modulator. The objective is to study the advantages of an adaptive structure over a conventional fixed QAM modulator.

A. VBR MPEG-1 Video Source

In the first experiment, a number of MPEG-1 encoded videos are used as the ATM traffic sources. An ATM call is considered a virtual channel that may include a number of video sources. These video sources and their traffic characteristics are shown in Table 1 [4]. The number of video sources simultaneously directed to a VP is a uniformly distributed random number between 0 and 30. The number of copies from a single video is also uniformly distributed and is between 0 and 5. Each call must introduce its traffic as well as its QoS parameters.

The required traffic parameters in this experiment were mean rate, the variance coefficient, and the Hurst parameter. The QoS parameters were probability of cell loss ratio and maximum tolerable delay. These parameters were generated using a random generator. The $D_{\max}$ is uniformly distributed between $1 \leqslant D_{\max} \leqslant 10$ msec, and $\log_{10}(P_{\mathrm{CLR}})$ is uniformly distributed in range -9 and -6.

The connection selects a particular VP randomly in this experiment. The system under study used three VPs when a VP initially carries a traffic with a mean rate between 1 kbps and 15 Mbps, a buffer size between 100 kbits and 1 Mbits, and a variance parameter α, between 10^4 and 5×10^5 bit-sec, respectively.

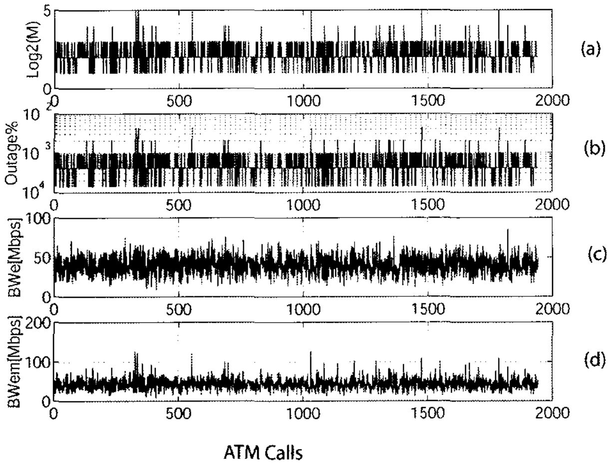

Fig. 12. Simulaton results for MQAM in a Ricean channel for video traffic constellation size variation according to ATM calls: a) Constellation distribution, b) outage probability, c) effective bandwidth, d) modified effective bandwidth.

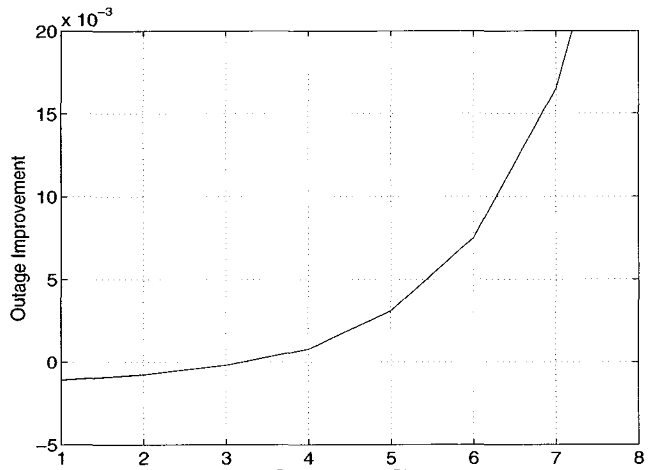

Fig. 13. The outage improvement of the adaptive modulator compared width fixed QAM in a Ricean channel for video traffic.

The Hurst parameter of VPs were also random between 0.75 and 0.95. The channel was considered to be burst. The average burst length of the channel was chosen a uniform random variable between 2 and 10. The traffic was transmitted through a LOS radio link. The link length was 10 km and operating frequency was 18 GHz. The height of transmit and receive antennas is selected as 7 m so as to achieve a LOS path of 14.3 km. Both antennas are parabolic dishes with diameters of 2 feet and a nominal gain of 38.9 dB. The power amplifier was assumed to be a commercial amplifier with power output of 23 dBm. Similar link has been studied in [12].

As a result of the traffic varieties of the ATM calls, a variable bandwidth was requested from network. The MQAM control unit estimated this demand by using the modified effective bandwidth metric. This demand is responded by MQAM level variation. The feasibility of using new modulation level is examined by the outage block. According to bandwidth demand, the constellation size is a variable between $M = 2$ and $M = 256$

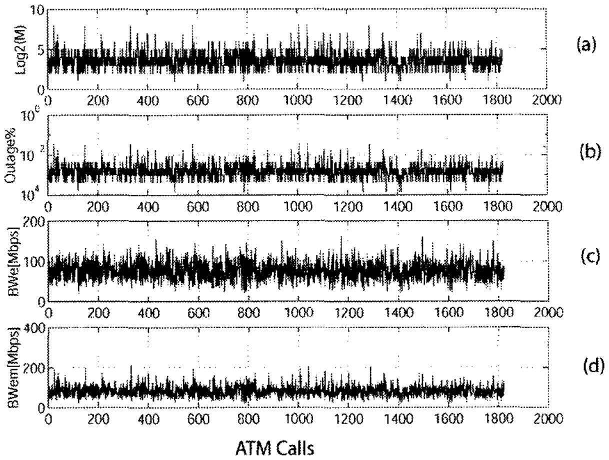

Fig. 14. Simulaton results for MQAM in a Ricean channel for multiple video traffic sources according to ATM calls: a) Constellation distribution, b) outage probability, c) effective bandwidth, d) modified effective bandwidth.

Table 2. Statistical parameters for MPEG-1 video traffic in a Ricean channel (effective nandwidth and modified effective bandwidth are in (Mbps)).

	M-level	Outage	BW_e	BW_{em}
Mean(Rice)	4.83	0.00054	40.26	43.58
Std.(Rice)	2.68	0.00038	11.51	14.17
Mean(Ray.)	5.49	0.00063	40.67	48.26
Std.(Ray.)	2.83	0.00040	11.27	14.47

$(1 \leqslant k \leqslant 8)$. An exact BER expression is used for $M = 2$ since (16) is only an upper bound for the BER for $M \geqslant 4$.

The objective of simulation was to obtain the distribution of the effective bandwidth (BW_{eff}), the modified effective bandwidth (BW_{meff}), the constellation size k, and the outage. It is assumed that the fading model in [26] is valid in presented scenario both with respect to the distance (2 km versus 10 km) and to the frequency (28 GHz versus 18 GHz). The fading model is Ricean with $K = 6$. The constellation size, outage, B_{Weff}, and BW_{meff} variations are shown in Fig. 12. As can be seen, according to the bandwidth demand, the constellation size, outage, effective bandwidth, and modified effective bandwidth change. The average and standard deviation of different parameters are shown in Table 2. These values only have a statistical meaning. The outage performance of an MQAM is also compared with that of the fixed QAM in Fig. 13. As an example, in Fig. 12 one sees that the demand to use a bandwidth more than 100 Mbps in a Ricean channel is very limited. Thus, an adaptive modulator frequently operates in lower modulation level (e.g., $k = 2$ and 3) and it improves the system outage. The outage improvement is due to using a lower modulation level compared with a 256 QAM conventional choice. The system can use the high modulation level when there is a high bandwidth demand. As seen from Fig. 13, the adaptive modulator offers a very significant improvement in performance over fixed high level QAM modulators.

Although a Ricean channel model is valid for a LOS link [16],

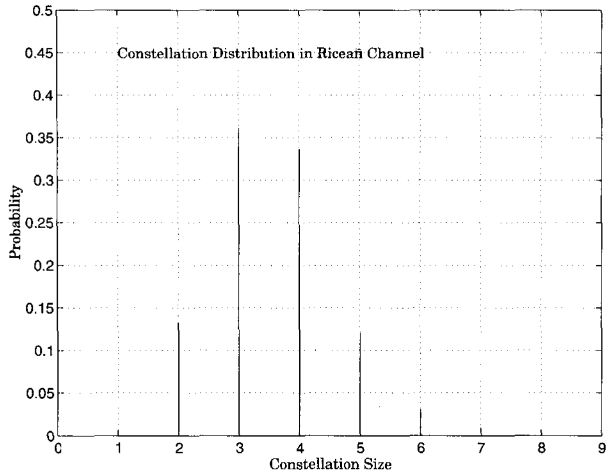

Fig 15. Constellation size distribution in a Ricean channel for multiple video traffic sources.

[27] (for example, an experimental study shows that a local multipoint distribution services (LMDS) link has a Ricean distribution [26]), and a fixed wireless ATM link must be studied under this category, a comparison between the operation of the adaptive MQAM modulator in Ricean and Rayleigh fading ($K = 0$) can also be quite useful. The statistical parameters are compared in Ricean and Rayleigh fading channels in Table 2. As can be seen, compared with the Ricean channel, while the effective bandwidth is almost same (traffic characteristics are independent from the channel), the constellation size and modified effective bandwidth has a higher average and variance. This behavior is due to nature of the Rayleigh fading.

B. *Multiple VBR MPEG-1 Video Sources*

In the previous experiment, a single ATM call is arrived and is directed to a particular VP at a time (a system with one input and one output). In this case, multiple ATM calls are simultaneously arrived and are directed to multiple VPs (a system with multiple inputs and multiple outputs). In this experiment, each VP was requested to transmit MPEG-1 videotraces between 0 and 30, and the number of copies from a single video is between 0 and 5. Table 1. shows the traffic characteristics of various video traffic sources. The initial values of VPs are similar to previous example. Fig. 11 shows the constellation size, outage, effective bandwidth and modified effective bandwidth variations in a Ricean channel.

Fig. 15 shows the constellation distribution in a Ricean channel for multiple video sources. As can be seen from Fig. 15, the variable bandwidth demand can also be seen in the highly aggregated traffic. A comparison between the different statistical parameters in Ricean and Rayleigh channels for multiple video sources can be seen in Table 3. As shown, the effective bandwidth is similar in Rayleigh and Ricean channels due to same input traffic. The average of the modulation level in Rayleigh channel is higher than that in Ricean channel. This is due to higher modified effective bandwidth requirements in a Rayleigh channel, and is a function of the parameter K in a Ricean model. This experiment shows that a Rayleigh channel requires 12 percent more bandwidth compared to a Ricean model with $K = 6$.

Table 3. Statistical parameters for multiple MPEG-1 Video Traffic in Ricean and Rayleigh Channels (Effective Bandwidth and Modified Effective Bandwidth are in (Mbps)).

	M-level	Outage	BW_{eff}	BW_{meff}
Mean(Rice)	16.81	.0022	76.61	82.20
Std.(Rice)	21.97	.0031	23.43	27.81
Mean(Ray.)	22.08	.0030	78.21	92.88
Std.(Ray.)	24.01	.0034	23.67	29.33

VI. CONCLUSIONS

An adaptive MQAM transmitter was proposed and designed to realize a fixed wireless ATM system. An effective bandwidth based on self-similar *(LRD)* model is used to estimate the required bandwidth of broadband traffic. The results of the statistical model show a very good agreement with simulation of the empirical video traces. The peak rate allocation compared with the effective bandwidth method and it was found that a high bandwidth saving can be achieved using this metric. It should be pointed out that this metric provides a better result for highly aggregated traffic. The impact of wireless channel on ATM traffic, which results in a HEC corruption and capacity variation due to channel fading, were studied. Two statistical models were discussed to examine the HEC corruption in a random and burst error. Moreover, the MQAM modulator capacity degradation due to multipath fading for transmission of the ATM traffic was analyzed. The study shows that this factor is a function of cell loss ratio and K factor in Ricean model. The effect of these degradations was used to define a capacity reduction factor for MQAM modulator in fixed wireless ATM link. Using effective bandwidth and capacity reduction factor, an overall metric of QoS in wireless ATM was defined. The metric was termed as modified effective bandwidth. This metric was used to control the level of an MQAM modulator. A performance study was conducted to evaluate the system performance under various VBR traffic. The study shows that the MQAM control unit highly saves the bandwidth while providing a guaranteed QoS in wireless networks. Moreover, the study shows that the MQAM control unit provides a flexible transmission system that highly improves the call acceptance and outage condition in wireless networks. The operation of a fixed wireless ATM link in Ricean channel was also compared with its operation in Rayleigh channel. For a similar effective bandwidth, the modified effective bandwidth metric demands more bandwidth in Rayleigh channel. The above results show that the modified effective bandwidth metric adequately characterize a fixed wireless ATM link.

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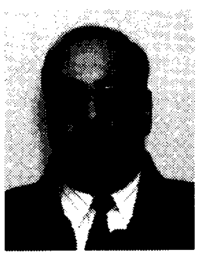

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