Dynamic Reconfiguration & Efficient Resource Allocation for Indoor Broadband Wireless Networks

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A combined Frequency and Time Division Multiple Access (FDMA/TDMA) mechanism for implementing an indoor broadband radio access system at 5GHz is described in [1] and [2]. The main feature of this approach is that real-time co-ordinated prioritised time slot assignments are performed in clusters of Access Points (AP's), which share the same carrier frequency. Re-use partitioning is performed in time by simultaneously assigning time slots within a cluster of AP's based on the expected level of interference and in frequency by allowing the carriers to be re-used by clusters of AP's that are sufficiently isolated. The AP cluster configuration is important for efficient utilisation of the scarce radio resources. If the clusters remain fixed then the system can support uneven load distributions within each cluster, but is not able to adapt to supporting load distributions which are unevenly distributed between clusters or to interference from other systems. In this paper a method of dynamically reconfiguring the clusters to support changes in the geographic load distribution over time and external interference is investigated. The performance in the presence of small scale signal fading is obtained and compared.

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Abstract : *A combined Frequency and Time Division Multiple Access (FDMA/TDMA) mechanism for implementing an indoor broadband radio access system at 5GHz is described in [1] and [2]. The main feature of this approach is that real-time co-ordinated prioritised time slot assignments are performed in clusters of Access Point's (AP's), which share the same carrier frequency. Re-use partitioning is performed in time by simultaneously assigning time slots within a cluster of AP's based on the expected level of interference and in frequency by allowing the carriers to be re-used by clusters of AP's that are sufficiently isolated. The AP cluster configuration is important for efficient utilisation of the scarce radio resources. If the clusters remain fixed then the system can support uneven load distributions within each cluster, but is not able to adapt to supporting load distributions which are unevenly distributed between clusters or to interference from other systems. In this paper a method of dynamically reconfiguring the clusters to support changes in the geographic load distribution over time and external interference is investigated. The performance in the presence of small scale signal fading is obtained and compared.*

1 Introduction

All radio communication systems attempt to provide reliable network services on a medium which is dynamically varying and difficult to predict. There is however a difference between radio systems which use dedicated spectrum and those which utilise unlicensed or license exempt spectrum, which is that in unlicensed systems must coexist in the same spectrum and can be deployed without any prior planning or authorisation. There is also a trend toward relaxation in the regulation of the way in which spectrum allocations are utilised, which is apparent in the recent 5GHz Unlicensed National Information Infrastructure (UNII) band allocation by the FCC in the United States and reflects an increasingly popular philosophy of allowing market forces to shape the way in which spectrum is used [3]. Therefore, to cope with interference from other types of radio systems and the signal fading which is inherent in radio communication systems because of multipath radio propagation phenomena, it is necessary to have a number of countermeasures. At the physical layer many techniques are commonly used to improve the reliability of the radio link, such as equalisation, multi-carrier modulation, antenna diversity, directive antennae, various forms of spread spectrum and channel coding. These techniques can be costly both in terms of complexity and the radio resources required and so adaptable solutions look attractive rather than assuming a certain maximum level of interference and fading. Flexible resource allocation has been shown to improve the performance considerably in personal communication systems [4], by attempting to achieve the optimum signal to interference ratio. However, these techniques assume that the entire radio resource allocation is under the control of a single radio system and that traffic is isochronous. Future broadband wireless systems operating in unlicensed spectrum will need to adapt to uncontrolled interference from other radio systems and the bursty nature of broadband traffic. This will require both flexible resource allocation and dynamic network reconfiguration. Reconfigurable radio networks have been studied for narrow band public cellular systems [5]. However, in narrowband systems there is more scope for implementing spread spectrum measures to reduce the impact of interference such as frequency hopping. Broadband solutions will generally have a smaller available bandwidth relative to the peak user data rate requirements which make such techniques less suitable.

In a radio access system, network reconfiguration can consist of handover of a terminal from one AP to another (inter-cell handover) or simply switching between channels on the same AP (intra-cell handover). The handover can be initiated by the signal degradation caused by fading and shadowing or by excessive interference being observed. The technique based on interference adaptation is described in [6] from a narrowband cellular personal communication systems perspective. The same technique can be used within broadband communication systems, but is complicated because of the bursty nature of broadband traffic. This causes bursty interference which is not easily predicted. However, assuming that interference will be concentrated on certain carrier frequencies for relatively long periods compared with the traffic bursts allows the same form of adaptation to be performed.

Broadband access systems must support both highly bursty and constant bit rate traffic with demanding delay and delay variation requirements. Radio resource allocation must be performed asynchronously, for bursty traffic, if the available frequency bandwidth is to be efficiently utilised. The technique proposed in [1] and [2] utilises a combined FDMA/TDMA approach with prioritised co-ordinated asynchronous time slot assignment. This allows bursty traffic to be supported efficiently within clusters of AP's by periodic time slot reassignment and measurement based time slot re-use. However, the configuration of clusters of AP's on different carrier frequencies was not fully addressed in this previous work. If the load distribution and radio interference is uniform then a static pre-planned cluster configuration would be possible as shown in figure 1. This is generally not the case as the load density is likely to fluctuate over time and space and there is no control over the occurrence of interference in unlicensed spectrum allocations. This means that the cluster configuration needs to adapt to provide the most efficient use of resources. The reconfiguration requires a planning process to allow AP groups to change from one carrier frequency to another. The reconfiguration process can be triggered by either the formation of new connections over a load threshold level (proactive) such as described in [7] or by the delay or packet error ratio becoming excessive (reactive), or indeed a combination of both of these. This paper investigates a reactive approach for triggering reconfiguration and evaluates the performance in the presence of external interference, load fluctuations and small scale Rayleigh fading. The mechanisms which cause Rayleigh fading are discussed in [8].

2 Simulation Model

A simulation model was developed which performs all the medium access control functions required for investigating the performance of the proposed FDMA/TDMA mechanism. The model contains representations of the radio nodes and AP's which perform time slot assignment, and plan the movement of AP groups between carrier frequencies. When a trigger occurs, the AP group that observes excessive delay or packet errors plans a movement to another frequency. However, if a previous plan to move to that frequency did not perform well, it is not repeated within a specified time period and another is chosen. The frequencies are selected in numeric order because it is difficult to reliably predict the performance of a change to a new carrier frequency without detailed knowledge of the other active nodes and the radio propagation environment.

The basic access point and Mobile Terminal (MT) cluster layout used is shown in figure 1. The bit rate that each carrier operates at is 20Mbits/s. Each AP (denoted by a zero in the last digit of the node identifier) has 4 mobile terminals associated with it which collectively form an AP group. Each carrier contains one cluster which consists of 7 AP groups. Initially, carrier 0 contains an additional AP group which is within radio range of the cluster of AP's on carrier 2 but not carrier 1. The snap-shot in figure 1 is the basic layout for all carriers. The traffic within each cluster area is evenly distributed between AP groups. An interfering node is positioned in the network coverage area and transmits a continuous signal at the same power level as the radio nodes within the system under investigation. The main simulation parameters utilised are indicated in table 1.

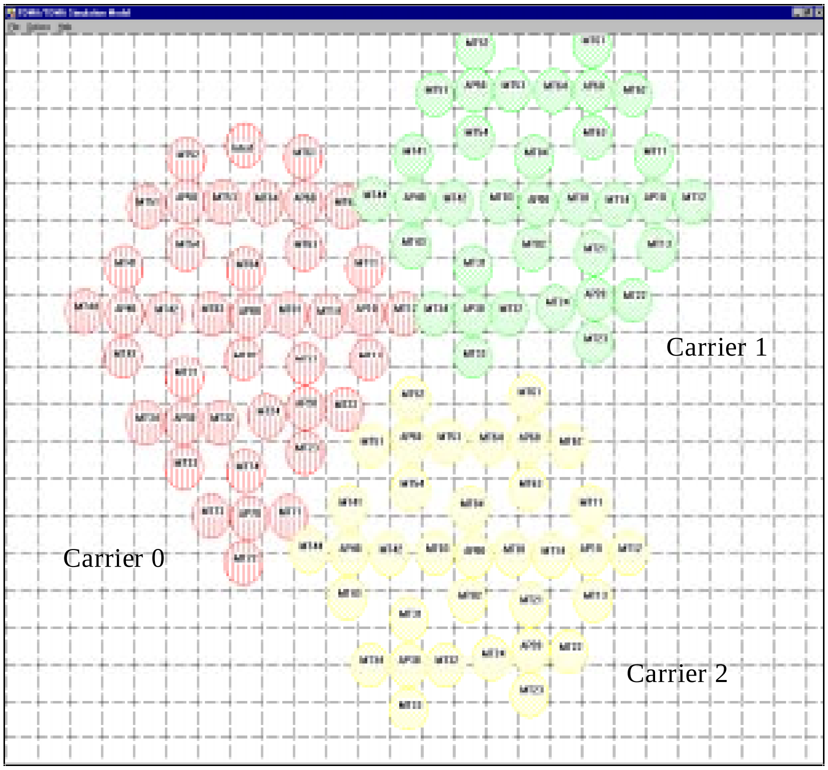


Fig 1 : Basic Simulation Layout with Interference on Carrier 0 (on a 10m x 10m grid)

Parameter	**Value**
Transmitter Power/Rate	200mW / 20Mbits/s
Path Loss Equation	43.5 + 10.y.Log(D) dB
Path Loss Exponent (y)	3.8
Node Separation	10-15m
AP Separation	~35m
Type 1 Message Size	6.5 kbytes Average
Type 2 Message Size	14 kbytes Average
Active Terminals per AP	4
Active Connections	1 per node

Table 1 : Simulation Parameters

There are two types of traffic, type 1 represents delay sensitive video traffic, with a 25Hz frame rate, (assumed to be using UDP/IP like network and transport protocols) and type 2 represents high volume TCP/IP data. A terminal can have either a type 1 or a type 2 connection with an access point or any other terminal within range and on the same carrier frequency. Time slot assignment is performed by AP's based on a pre-emptive priority discipline with type 1 having precedence over type 2. Polling is used to determine the buffer occupancy at MT's associated to each AP. Time slot re-use is allowed with an interference threshold for type 1

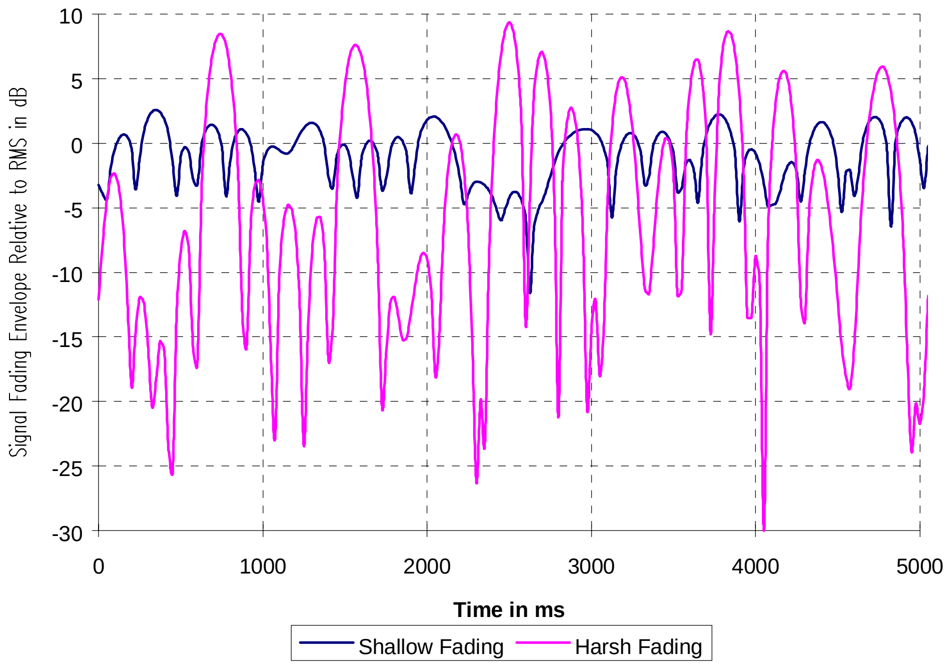


Fig 2 : Small Scale Fading Envelope over Time

and 2 traffic being 15 and 10 dB below the acceptable signal level threshold respectively. There is assumed to be a random variation in the acceptable signal threshold between nodes (of 0 to 7dB), due to variability in the accuracy of measurements, with a minimum value of -65dBm. A MAC level stop and wait ARQ is implemented for type 2 traffic to ensure high integrity data delivery. Type 1 packets are delivered even if they contain errors. This is the reason why the interference threshold is lower for type 1 traffic.

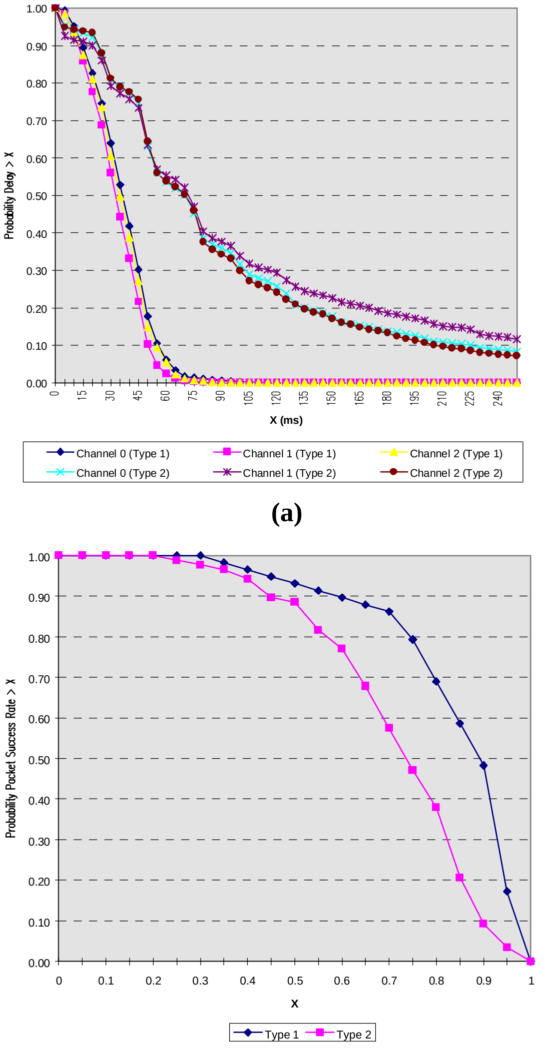
The radio path loss is assumed to consist of a constant attenuation component given by the equation in table 1 and a small scale Rayleigh fading component, which is caused by movements in the environment. The small scale fading can be either harsh or shallow depending on whether there is a dominant component or not. Signal distortion caused by time dispersion is assumed to be mitigated by channel coding and multi-carrier modulation or equalisation. Large scale fading caused by shadowing of nodes is assumed constant over the simulation period. A switched antenna diversity mechanism is assumed to be employed using two spatially separated antennae which give independent fade distributions. The receive antenna selection is assumed to be performed at the beginning of each transmission, based on power level measurement.

A configuration change is triggered, when the average amount of type 1 data waiting transmission per frame in an AP group over 5 successive frame duration’s (equivalent to 125ms) exceeds 20kbytes. Alternatively, if the number of type 1 packet errors over 5 successive frame duration’s exceeds 1/3 of the total number transmitted. The trigger is reactive to congestion or excessive packet errors caused by interference, fading or fluctuations in load. However, the reactions observed in the simulations are mainly due to interference and fading.

3 Results

The results with shallow small scale fading (the envelope of which is shown in figure 2) were obtained with a type 1 traffic load of approximately 30Mbits/s, it is assumed that the type 2 connections attempt to operate at the maximum available rate (i..e. such as would happen for intensive file transfer or Web browsing applications). Figure 3a shows the message delay performance obtained if reconfiguration is performed and there is harsh small scale fading. The packet success rate distribution shown in figure 3b indicates that 50% of active type 1 connections experience worse than 0.9 packet success rate, and around 5% experience only 0.5 packet success rate. This would not be acceptable presuming that each packet failure results in a frame loss in the video sequence. Figure 4a illustrates that better delay distributions can be obtained for type 2 of traffic with shallow fading which would be more typical of what would be expected an indoor channel with a dominant multi-path signal component. However, the type 1 traffic delays are slightly higher because of the frequency of reconfigurations taking place, which is due to the fact that the relative fade duration is longer even though the depth is less severe. Figures 4b indicates that over 85% of type 1 connections experience a packet success rate of 0.9 or better.

The results without any reconfiguration being performed are shown in figures 5 and 6. Figure 5a indicates the delay distribution obtained in the presence of harsh fading is poor on channel 0 for type 2 traffic and consequently the total throughput is much lower, (54Mbits/s compared to 77Mbits/s with reconfiguration) Figure 6b shows that 10% of type 1 connections observe worse than 0.5 packet success rate. Similarly for shallow fading, figure 6a indicates that the delay performance is poor on channels 0 and 1 and again only 55Mbits/s throughput is obtained. However, good delays are obtained for type 1 traffic on all channels. Figure 6b illustrates that a packet success rate of 0.9 is achieved by almost 90% of connections, but around 5% of connections experience a very poor success rate. These are the connections located near to the interference.



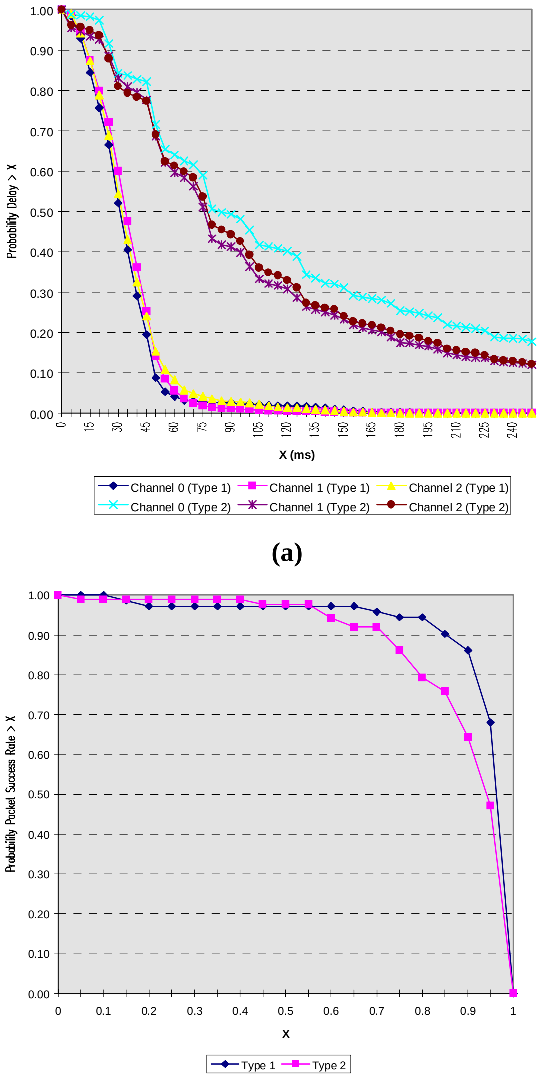
(a)

(b)

Fig 3 : Message Delay Distribution (a) and Packet Success Rate Distribution (b) with Interference on Channel 0 and Harsh Fading (77Mbits/s Total Throughput)

4 Conclusions

The results show that a good performance can be obtained for type 1 and 2 traffic in the presence of interference with dynamic reconfiguration of the carrier frequencies which AP groups occupy. The use of a trigger mechanism that is based on the average buffer occupancy and error rate over a time period (125ms in this case) allows highly bursty interference, rapid fading and short term load fluctuations to be ignored. However, longer term interference and load variations do reliably trigger reconfiguration. In the presence of harsh small scale fading the performance with reconfiguration is reduced because of unnecessary frequency changes, but the delay distributions are fairly balanced between carriers. In practice, the fading will most likely be shallow in an indoor environment particularly if a line of sight exists between nodes. Therefore, the reconfiguration mechanism should provide closer to the expected performance with shallow fading.

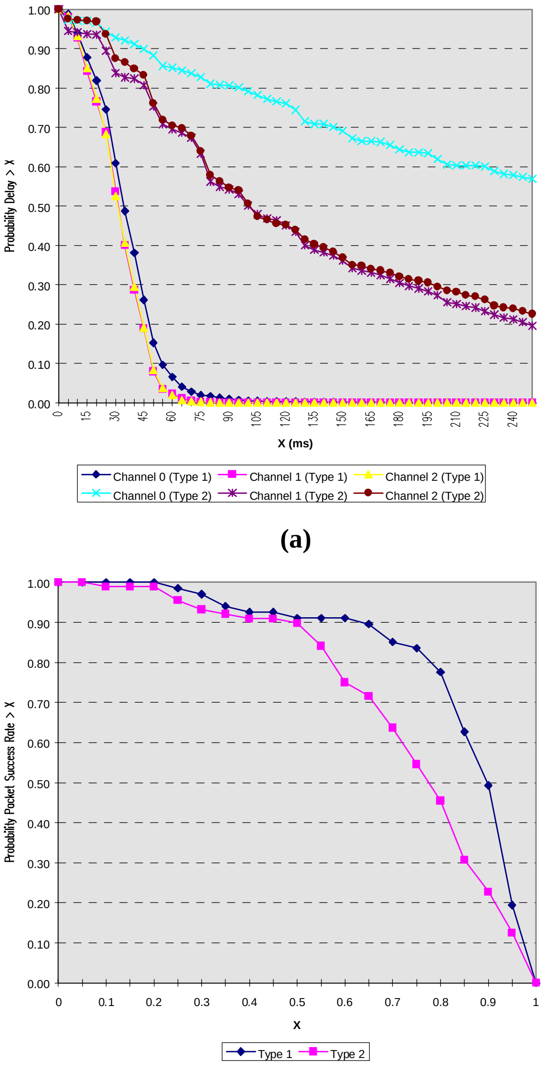


(a)

(b)

Fig 4 : Message Delay Distribution (a) and Packet Success Rate Distribution (b) with Interference on Carrier 0 and Shallow Fading (68Mbits/s Total Throughput)

The use of proactive trigger mechanisms has not been considered in this paper and requires further investigation. It is difficult to predict performance because of the dynamic nature of the bursty traffic and radio propagation. Therefore proactive mechanisms will either be pessimistic and limit performance, or optimistic and potentially cause performance degradation when, for instance, a new call admission is accepted. There is also a need for proactive regrouping of clusters when the load and interference reduces, to improve packet success rate of active connections. Further evaluation is also necessary to assess how inter-cell node handover and group frequency changing can be integrated into a single solution. Clearly, node handover is necessary when the performance of a single link degrades whereas group reconfiguration is necessary when the whole group performance degrades. Only the latter has been considered in this paper.



(a)

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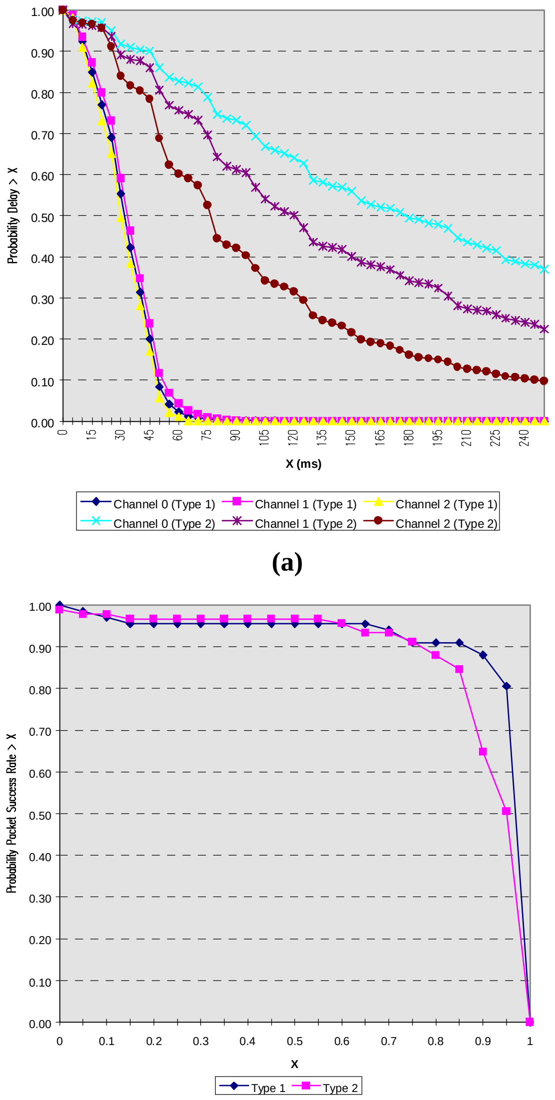
Fig 5 : Message Delay Distribution (a) and Packet Success Rate Distribution (b) with Interference on Channel 0 Harsh Fading but no Reconfiguration (54Mbits/s Total Throughput)



(a)

(b)

Fig 6 : Message Delay Distribution (a) and Packet Success Rate Distribution (b) with Interference on Carrier 0 Shallow Fading but no Reconfiguration (55Mbits/s Total Throughput)

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