A Combined Frequency and Time Based Channel Reuse Partitioning Multiple Access Technique for Indoor Wireless ATM Networks

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This paper describes a multiple access technique suitable for indoor wireless ATM networks that exploits both frequency division and time division techniques for channel re-use (i.e. FDMA/TDMA). The novel feature of the proposed technique is that co-ordinated, prioritised TDMA is supported for clusters of Access Points (AP's) using measurement based time slot assignments. This has the advantage of easily supporting uneven load distributions and allowing rapid handover between AP's on the same frequency carrier. The proposed technique can also support bursty traffic efficiently by periodic time slot re-assignment, which is an important consideration for wireless ATM systems. Results are presented of the performance of the proposed technique and are compared with a conventional FDMA/TDMA strategy.

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Abstract

This paper describes a multiple access technique suitable for indoor wireless ATM networks that exploits both frequency division and time division techniques for channel re-use (i.e. FDMA/TDMA). The novel feature of the proposed technique is that co-ordinated, prioritised TDMA is supported for clusters of Access Point's (AP's) using measurement based time slot assignments. This has the advantage of easily supporting uneven load distributions and allowing rapid handover between AP's on the same frequency carrier. The proposed technique can also support bursty traffic efficiently by periodic time slot re-assignment, which is an important consideration for wireless ATM systems. Results are presented of the performance of the proposed technique and are compared with a conventional FDMA/TDMA strategy.

Introduction

The architectures of future indoor broadband access networks will support broadband service delivery in many environments with both stationary and mobile end terminal devices. Wireless broadband access is not an alternative to cable access, but will provide complementary features which are attractive in some of the deployment environments. In particular, wireless access systems can provide continuous service to mobile terminal devices while they are moving. However, wireless can not compete with the high bandwidths provided by fibre optic cables which will be necessary for high performance multimedia terminals. Wireless access also has the potential to support direct peer-to-peer interaction between devices, which is attractive particularly for devices within the home. For instance between a portable multimedia terminal and a digital TV. Alternatively this can be achieved utilising a switching function within the broadband network to which the wireless AP is connected. However, the efficiency benefits of performing direct peer-to-peer connections is significant if this type of interaction occurs frequently. It is clear that the utilisation of wireless access to broadband networks will enable enormous flexibility in the way in which they are deployed and utilised. A view on how broadband indoor access networks may emerge is illustrated in figure 1.

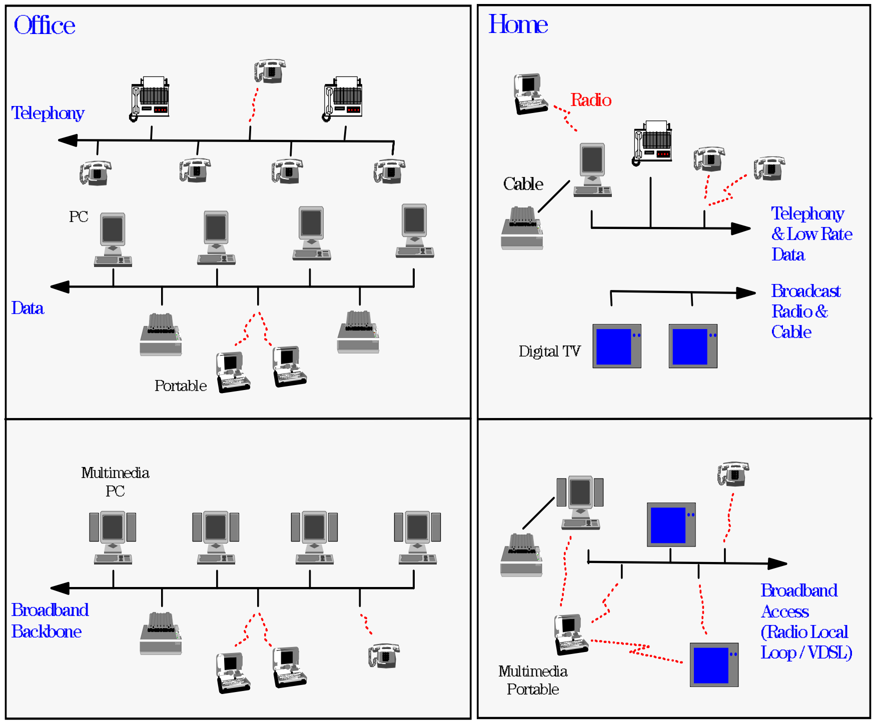


Figure 1 : Migration to Broadband Networking in the Office and Home

Broadband services not only require high bandwidth radio channels. It is also necessary that quality of service parameters are met and maintained. High data rate digital radio systems exhibit error characteristics that are caused by the demodulation of radio signals which have undergone multipath propagation, Doppler frequency and phase shifting, shadow and frequency selective fading and have additive noise and interference. Therefore, the error characteristics are time varying even if the radios are stationary. The protocols required to counteract the errors introduce inefficiency and delay. For the above reasons, broadband wireless communication networks will have limited network coverage areas, either within buildings or outdoor public areas. They will only support mobile terminals moving at walking or running pace and not high speed vehicles. Alternatively, if the end termination are not mobile the coverage area could be extended for local loop or last mile delivery of broadband services to residential or business premises. These two types of system (mobile and static) could be both publicly or privately operated. It could also be possible for a static and mobile network operated by public and private operators respectively to be interconnected. This would be the case if wireless delivery of broadband services to a building is integrated with a wireless broadband network within the building.

Indoor wireless access will need to support system loads which may not be uniformly distributed and allow roaming in building size coverage areas, (or possibly limited size open public spaces). Low power short range radios are needed to provide the necessary high data rates, but result in a large number of radio AP's. Multiple access techniques which exploit the re-use benefits of low power radios and adapt to the indoor propagation environment and cope with bursty traffic with various data rates, while supporting rapid handover between AP's are most suitable for broadband access networks. Packet CDMA and dynamic TDMA (D-TDMA) are two candidate protocols. However, there are significant implementation difficulties with very wideband packet CDMA systems. The narrowband TDMA protocols considered in previously published work such as [1] do not support combined FDMA/TDMA channel assignment or perform re-assignment over relatively long periods of time as in [2] and consequently can not support highly bursty traffic efficiently in a wireless broadband system. The technique considered in this paper supports statistical multiplexing of bursty traffic by use of D-TDMA, and combines time and frequency division based re-use partitioning. The advantage of this approach is that highly bursty traffic and non-uniformly distributed loads can be accommodated more efficiently than with conventional FDMA/TDMA techniques using fixed and dynamic channel assignments.

Multiple Access Technique

ATM utilises fast packet switching to achieve efficient utilisation of channel bandwidth with bursty traffic. This property is only fully exploited when there is a statistically significant number of bursty traffic virtual circuit connections sharing a high capacity channel. In order that a multiple access technique can also exploit this property, a large number of mobile terminals must share the same high capacity channel. However, in general, increasing data rate reduces the effective range (assuming the same transmit power), and implies that the number of terminals with the potential to share the channel is reduced (if the mobile terminal density remains constant). Therefore, frequency division re-use partitioning which assigns carrier frequencies on an AP basis can not exploit this property if there is not a significant number of active terminals per AP coverage area. Re-use partitioning based on spread spectrum techniques can exploit the full statistical multiplexing benefits of the wideband channel. However, if uncoordinated access techniques are used by each terminal using a different pseudo-random code, the probability of colliding transmissions occurring with the potential to cause errors, increases steeply with the network load. Also, either high speed frequency agility (for frequency hopping solutions) or very wideband transmission (for direct sequence) is required which is generally difficult to implement. Alternatively, a Dynamic Channel Assignment (DCA) scheme using measurement based channel selection can allocate carriers and time slots without co-ordination. This is the technique used in the DECT dynamic channel selection mechanism. However, the performance relies on the channels being continuously occupied once selected and relinquished when not being used to minimise conflicting assignments. This is not efficient if the traffic is highly bursty and the burst duration is short relative to the time taken to select channels (such as video and data traffic). Also, it can not support prioritised channel assignments based on traffic type.

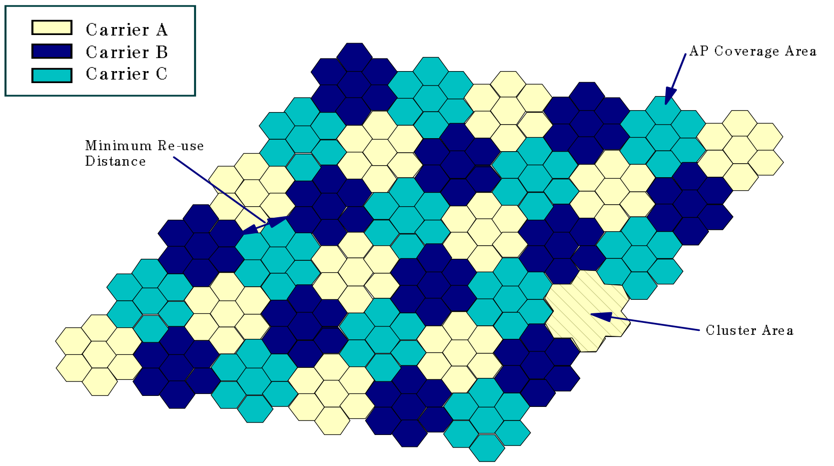
The proposed technique is based on a DCA approach using measurement based co-ordinated channel assignments with periodic time slot re-assignment. It is proposed that clusters of AP's of a limited size share the same frequency carrier to relax the accuracy of synchronisation required for efficient channel utilisation, and to limit the overhead required to distribute time slot assignment information. Therefore, synchronisation can be implemented by a clock signal multicast from an elected primary AP to all other AP's in a cluster area over the fixed infrastructure or by a distributed synchronisation mechanism (such as described in [3]). This is not feasible with the required accuracy if the cluster area is too large but it can be achieved easily with small cluster areas consisting of up to 9 AP's. The frequency division partitioning mechanism is required if the network coverage area is larger than the cluster area (see figure 2). Fewer frequency carriers are needed than in conventional narrowband FDMA/TDMA solutions because the cluster area consists of a number of AP's and so is larger than a single AP coverage area. If there are 7 AP's per cluster area and 3 carrier frequencies the minimum C/I caused by co-channel interference is about 18dB (assuming cluster areas as in figure 2a and path loss distance exponent of 3.8). Handover between AP's in different carrier frequency cluster areas is less critical than between AP's in the same cluster area because it will occur less frequently.

In contrast, a conventional FDMA/TDMA approach would require at least 7 frequency carriers for the same 18dB minimum C/I performance. If the available bandwidth is divided between 7 carriers instead of 3, each carrier will support 3/7ths of the capacity. In the case of a fixed channel assignment strategy each AP would be assigned a single carrier. Therefore, the opportunity for channel sharing on each carrier is greatly reduced for the same AP coverage area and terminal density. This could prevent any statistical multiplexing from being performed if there are only a few active terminals per AP. It also prevents the capacity from being re-distributed in any particular part of the cluster area. If the AP coverage area is increased to equal the cluster area by increasing transmitter power, then the number of terminals per channel is the same but the available channel capacity for the terminals is 3/7ths of the proposed approach, which is clearly undesirable as capacity per unit area would also be 3/7ths. Note that with the proposed approach, the raw channel capacity per unit area is 1/3rd of that achieved with the conventional approach, because there are three channels, one per cluster area and there are 7 AP's per cluster. This reduction in raw area capacity would be unacceptable if the load is evenly distributed geographically and the traffic characteristics are constant bit rate. However, the load is not likely to be evenly distributed in wireless ATM networks even when the terminal density is uniform. The traffic is also likely to be highly bursty in nature for video and data applications. The proposed approach can also adapt to uneven load distribution between cluster areas occurring over longer time periods by adjusting the cluster area sizes as shown in figure 2b, while still efficiently re-using the carriers. Adjacent cluster coverage areas could be over-lapped to support even higher loads if more than 3 carriers are made available.

The proposed Asynchronous Time Division Multiplexing - Multiple Access (ATDM-MA) technique is described in [4]. It assigns and reassigns time slots on a periodic basis using an algorithm which utilises a priority discipline based on the supported traffic types which are shown in table 1. The asynchronous service for traffic 1 and 2 attempts to serve the data units in the transmission buffers each frame period, type 1 having priority over type 2. In order to perform statistical multiplexing on a burst scale, the data units correspond to bursts of ATM cells and the frame rate must be higher than the burst arrival rate. Traffic which has a burst arrival rate that is higher than the frame rate can not be efficiently accommodated by this approach. Therefore, a synchronous time slot assignment process is utilised for type 0 traffic. It is proposed that video traffic will be the predominant type of traffic in future wireless access networks and so video burst arrival rates must be supported. Video traffic has periodic bursts with 25 or 30Hz frequency, therefore a ~40Hz frame rate will easily accommodate this type of traffic.

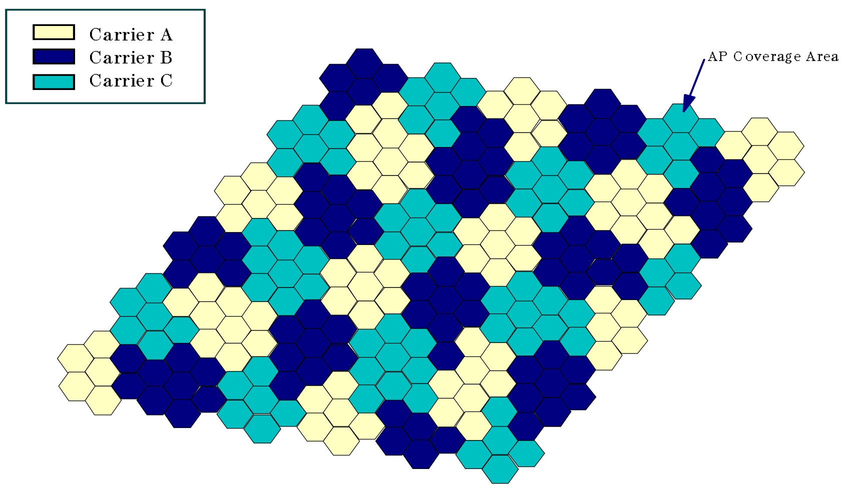
Type	Description	Example Service	Slot Assignment Mechanism
0	Constant bit rate	Voice telephony	Peak rate synchronous
1	Variable bit rate	Video	Asynchronous using fully gated limited polling
2	Available bit rate	Unicast data	Asynchronous using fully gated limited polling
3	Unspecified bit rate	Multicast data	No slots assigned (random access mechanism in empty slots)

Table 1 : Traffic Types Supported



(a)

Possible Reconfiguration for Uneven Load Distribution



(b)

Figure 2 : Relationship of Cluster and AP Coverage Areas
(a) even load distribution (b) uneven load distribution

In order to perform channel re-use within a cluster area the ATDM-MA technique utilises radio power measurement based interference assessment in the assignment process. For this to be effective, the frame rate must be high enough to ensure that the radio channel quality does not change significantly during this period. Clearly short term variations in the channel quality due to inter-symbol interference and frequency selective fading can not be taken into consideration and other techniques such as channel equalisation or multi-carrier modulation and antenna diversity are required. However, longer term fluctuations due to shadowing effects can be taken into consideration with a frame rate of ~40Hz in indoor and limited range outdoor environments as discussed in [5]. The overheads associated with assigning time slots depends on the number of time slots per frame and the re-assignment frequency (or frame rate). The overheads will not be excessive with ~40Hz frame rate and <100 slot bursts per frame.

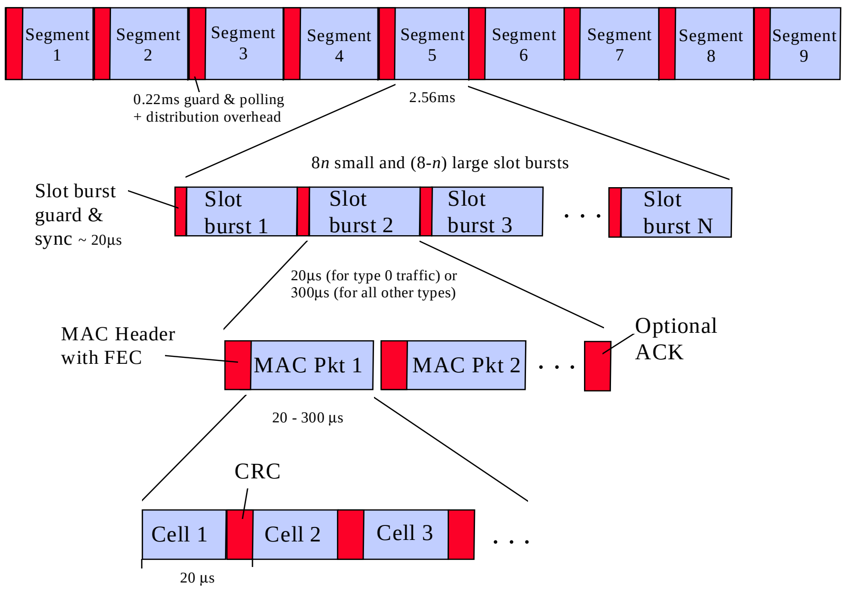


Figure 3 : ATDM-MA Frame Structure @20Mbits/s

The proposed frame structure is illustrated in figure 3 which assumes a 20Mbits/s channel data rate. The large slot bursts are each 320µs in duration and there are 72 per frame, which are arranged in segments. Each slot can be allocated to a particular terminal or AP, which utilises MAC packets to transfer ATM cells. A retransmission mechanism is assumed to be needed for traffic classes requiring high integrity cell delivery. Therefore, acknowledgement (ACK) packets are necessary to implement either stop and wait, go-back-N or selective repeat retransmission schemes. Each MAC packet contains ATM cells corresponding to a single virtual circuit connection. Therefore, the ATM cell header information is contained in the MAC header and ATM cell headers can be removed and reformed at either end of the wireless link. A 2 byte CRC is utilised on ATM cell payload information to detect errors.

Time Slot Assignment Process

In an access network configuration, time slot assignments are performed by a scheduler function at each radio AP and the information is distributed to other schedulers within a cluster area over the fixed infrastructure. In other configurations in which a fixed infrastructure may not exist the information must be distributed by other techniques (such as a multi-hop flooding mechanism discussed in [4]). Each AP performs assignments for a frame duration at a time in a sequential manner (offset by a segment duration) to prevent conflicting assignments. Interference power thresholds are utilised to determine whether simultaneous transmissions will cause interference at the receiving terminals. This information and the status of the transmit buffers within mobile terminals is obtained by a polling mechanism which occurs at the beginning of the segment. Slot assignments are distributed to the mobile terminals registered with an AP at the end of the corresponding segment.

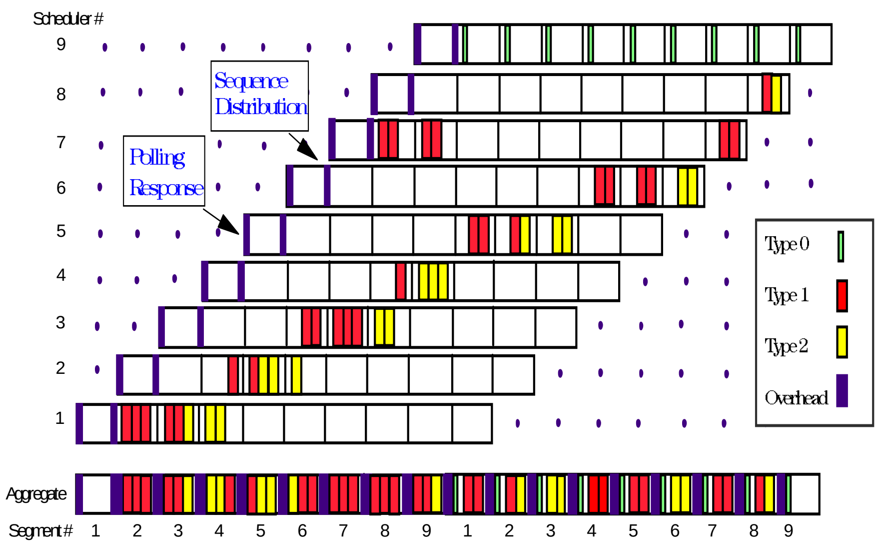


Figure 4 : Example Slot Burst Assignment using ATDM-MA

Figure 4 illustrates the assignment process with 9 schedulers sharing the same carrier frequency. The type 0 traffic has the highest priority and is assigned smaller time slots on a synchronous basis (i.e. either the same slot every segment or every frame). This enables type 1 and 2 traffic to be assigned slots in an asynchronous manner every frame period. A type 1 assignment can pre-empt a type 2 assignment providing the slot is in the frame period. Type 3 traffic is not assigned slots but utilises any empty slots to perform random access.

Simulation Model

A computer simulation model was developed to investigate the proposed multiple access protocol with two classes of traffic. The first class (type 1) is assumed to represent compressed video with a 25Hz burst arrival frequency. The second (type 2) represents bursty data with a Poisson burst arrival distribution. The sizes of bursts have an inverse exponential distribution in both cases. Type 1 traffic has priority over type 2 in the slot assignment process. The two types of MAC packet used to transfer the cells are not multiplexed within the same time slot burst. A simple stop and wait ARQ is used on MAC packets containing type 2 traffic to ensure reliable cell delivery, whereas the delivery of Type 1 cells containing errors is acceptable. The key parameters utilised in the simulations are summarised in table 2. Simulations were conducted with 7 AP's within a cluster area, a channel data rate of 20Mbits/s, 20µs time slots and a frame rate of 40Hz. In order to determine how the proposed technique performs with relation to a conventional approach with 7 channel frequency re-use partitioning, a second scenario was simulated with a 8.57Mbits/s channel data rate which is 3/7ths of 20Mbits/s to utilise the same overall bandwidth (assuming the same modulation efficiency). In this case the slot size equals 46.67µs with a frame rate of 47Hz and interference measurements are not passed in the polling responses. Adjacent channel interference is ignored in both cases.

Parameter	**Value**
Transmitter Frequency / Power	5GHz / 100mW
Path loss equation (in dB)	40.5 + 10.y.Log(distance in m)
Path loss distance exponent (y)	3.8
Interference threshold	-80, -77 dBm
Acceptable signal threshold	-60dBm
AP separation	~33m
Active Terminals per AP	4
Average cell burst size (Type 1)	120 cells (minimum 100 cells)
Average cell burst size (Type 2)	25 cells (minimum 1 cell)

Table 2 : Main Simulation Parameters

The simulation scenario is shown in figure 5 for the proposed approach. The same number of AP's and active terminals on a single carrier is simulated for the conventional approach. However, the AP's are spaced at 2.5 times the AP separation, which assumes hexagonal coverage areas as in figure 2. The simulation model limits the number of simultaneous type 1 traffic connections to 10. The type 1 traffic connections are randomly distributed but concentrated in 3 out of the 7 AP areas for the proposed approach and either 3 or 5 out of 7 for the conventional approach. Type 2 traffic connections are randomly distributed between all 7 AP areas. The results in table 3 summarise the performance of the simulations and show that the proposed approach provides superior throughput for type 2 traffic at 50ms cell burst delay on a single carrier. The conventional approach provides superior throughput for type 2 traffic if higher delays can be tolerated. The proposed approach also achieves a significantly lower cell burst error ratio because it actively controls the amount of co-channel interference. Even when the interference threshold is raised to -77dBm, the error ratio for the type 1 traffic is lower than type 2 because of the concentration of connections.

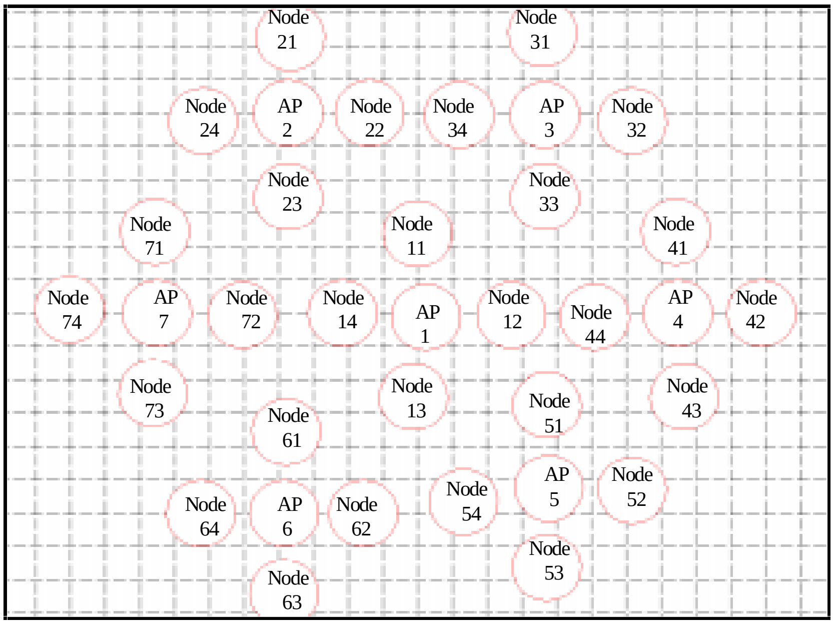


Figure 5 : Simulation Layout for Proposed Approach (with 5m X 5m grid)

Parameter	**Proposed Approach (Interference threshold)**		**Conventional Approach**
	-80dBm	**-77dBm**	
Throughput (for type 2 traffic at 50ms burst delay)	3.8 Mbits/s	5 Mbits/s	4.8 Mbits/s
Type 2 : packet retransmission ratio	$2x10^{-3}$	$6x10^{-1}$	$5.1x10^{-1}$
Type 1 : cell error ratio	$2.7x10^{-4}$	$6x10^{-3}$	$3.7x10^{-2}$

Table 3 : Results Summary (with type 1 connections in 3 out of 7 AP areas)

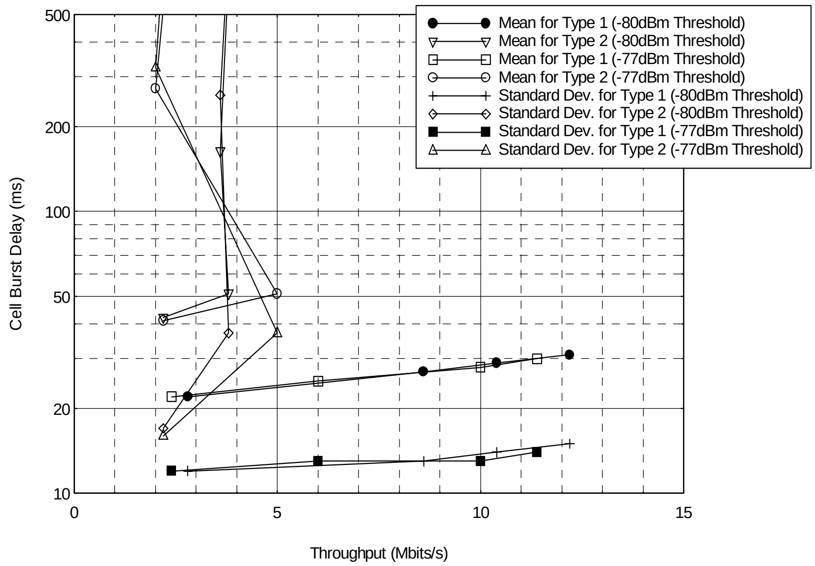


Figure 6 : Cell Burst Delay Vs Throughput (Proposed Approach)

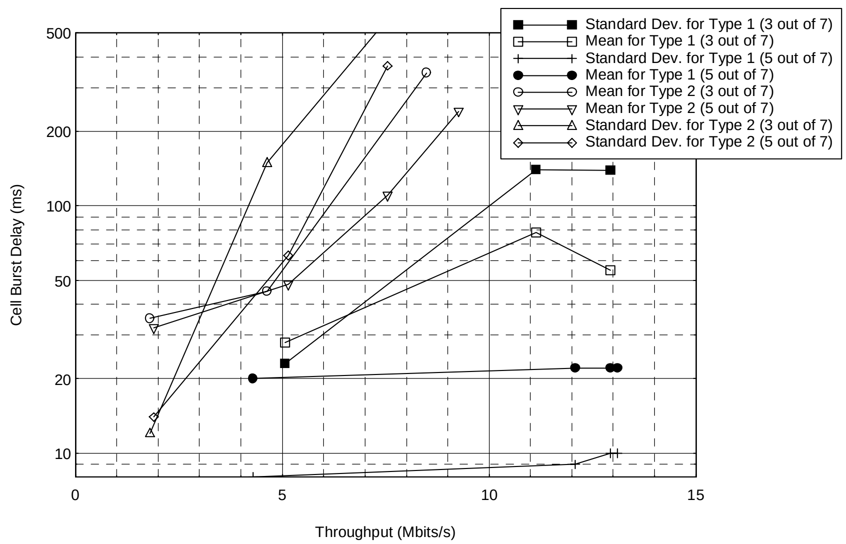


Figure 7 : Cell Burst Delay Vs Throughput (Conventional Approach with type 1 traffic connections concentrated in 3 and 5 out of the 7 AP areas)

The throughput and delay results are shown in figures 6 and 7. Figure 6 indicates that the proposed approach can provide a mean and standard deviation of cell burst delay of 30 and 15ms respectively. This is significantly better than the conventional approach with type 1 traffic concentrated in 3 out of the 7 AP areas, which is shown in figure 7 to be 80 and 140ms respectively.

With type 1 traffic concentrated in 5 out of the 7 AP areas the delay performance is better for the conventional approach because of the shorter frame duration (47Hz compared to 40Hz).

Conclusions

The proposed multiple access technique can support delay sensitive bursty traffic connections with high peak cell rates and cell burst sizes with better throughput, burst transfer delay and delay variation compared with a conventional FDMA/TDMA approach. It also simplifies handover between AP's within the same cluster area which can consist of up to 9 AP's. The technique can adapt to the unpredictable indoor propagation environments and is able to support traffic loads that are not uniformly distributed (in time and location) and virtual circuit connections of various cell rates with different relative priorities which are important requirements for indoor broadband wireless access networks. It can also provide direct peer-to-peer connections between terminal devices in the same cluster area, which is more efficient than routing through a network switch for interactions between terminals in close proximity. The time slot assignment algorithm can be improved by using a least interference or least interference below a threshold time slot assignment algorithm as described in [6]. Different thresholds for different traffic types could also be used if their cell error ratio requirements are significantly different.

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