Dynamic CDMA/TDMA band based scheme for wireless communication

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Abstract:

In this paper, we design a dynamic frame length CDMA/TDMA scheme for clustered wireless ad hoc networks with unknown traffic parameters. In this scheme, the collision-free intra-cluster commu nications are organized by the cluster-heads using a TDMA scheme, and a CDMA scheme is overlaid on the TDMA to organize the interference-free inter-cluster communications. Therefore, to design such a scheme, we encounter three important problems, namely cluster formation, code assignment, and slot assignment. In this paper, we propose three algorithms to solve the addressed problems based on learning automata. In our scheme, by the proposed clustering algorithm, the wireless hosts are grouped into non-overlapping clusters. Then, by the proposed code assignment algorithm (considering the concept of code spatial reuse), an interference-free code is assigned to each cluster. Finally, by the slot assignment algorithm, each cluster member is assigned a fraction of TDMA frame proportional to its traffic load. The simulation results show that the proposed CDMA/TDMA scheme outperforms the existing methods in terms of almost all metrics of interest, specifically, under bursty traffic conditions.

Keywords:

CDMA or TDMA; Slot assignment; Code assignment; Cluster formation

INTRODUCTION:

CDMA is a spread spectrum multiple access scheme in which a transmitter spreads the information signal in a wide frequency band by using a spreading code. A receiver uses the same code to retrieve the received signal as well. This approach provides multiple accesses by allowing the simultaneous transmission by different nodes, and is employed to reuse the bandwidth and to reduce the interferences. In CDMA scheme, each group of nodes can be given a shared code. Many codes occupy the same channel, but only nodes associated with a particular code can understand each other. If the codes are orthogonal, or nearly so, so that any bit errors caused by co-channel interference can be handled by forward error correction, multiple nodes may occupy the same band. In the spread spectrum CDMA system, each node needs to know which code must be used for transmitting or receiving a particular packet. Indeed, the receiver should be set to the same code as the designated transmitter. Since the number of available codes is limited, it is impossible to assign a unique code to each transmitter or receiver, and so the concept of the code spatial reuse seems to be promising. In a clustered network, this means that two or more non-neighboring clusters can be assigned the same code. An interference-free code assignment problem is similar to the vertex coloring problem in which the neighboring nodes (clusters) are refrained from choosing the same colors (codes). Graph coloring problem is known to be NP-hard (Karp, 1972). In TDMA scheme, a single channel is time-shared. That is, use of the channel is divided among several hosts by allowing each host to access the channel periodically, but only for a small period of time referred to as time slot. A set of such periodically repeating time slots is known as the TDMA frame. During a time slot, the entire bandwidth is available, and then the host must relinquish the channel. A given host may be assigned more than one time slot in each frame. Since the channel is only available to one of the hosts at a time, TDMA is a collision-free scheme. Difficulties with TDMA largely center on the problem of synchronizing a number of independent hosts. To cope with this problem a perfect synchronization between the hosts is required, and guard band is proposed as a solution to relieve the impact of synchronization errors, clock drift during the slot, and differences in propagation delay between the hosts. Indeed, a guard band is period of time during which the channel is assigned to no host. Owing to the small size of the time slots, guard bands results in a significant overhead for the system . Although the TDMA scheme is essentially a half-duplex mechanism in which only one of the two communicating hosts is able to transmit at a time, the small duration of the time slots gives the illusion of a two-way simultaneous communication. In CDMA scheme, simultaneous transmissions can be isolated by using different spreading codes. However, a node in a spread spectrum CDMA system needs to know which code should be used for transmitting or receiving a particular packet. In this scheme, a unique code is assigned to each transmitter and this is a trivial problem if the network size is small. But, when we employ the CDMA scheme in a large multi-hop ad-hoc network, the code assignment becomes an intractable problem. The concept of the code spatial reuse is a well-known solution reported in the literature by which a host of connections can be handled with a minimum number of codes. Another promising approach to solve the code assignment problem is using the CDMA/TDMA technique. To design an overlaid CDMA/TDMA scheme, three following issues must be considered. First, grouping the hosts into a number of non-overlapping clusters, second, assigning a code to each cluster so that no two neighboring clusters have the same code, and finally, using an efficient TDMA-based slot assignment scheme within each cluster. Many studies have been carried out on the CDMA/TDMA scheme in cellular networks,while in ad-hoc networks, it has not received the attention it deserves. Gerla and Tsai (1995) proposed an overlaid CDMA/ TDMA channel access scheduling scheme for a clustered multi- hop wireless network. In Gerla and Tsai (1995), the authors also proposed a distributed cluster formation algorithm. The cluster- heads act as local coordinators to resolve channel scheduling, perform power measurement/control, maintain time division frame synchronization, and enhance the spatial reuse of time slots and codes. Using a CDMA scheme, an interference-free code is assigned to each cluster, and a TDMA scheme is used within the clusters. Richard Lin and Gerla (1997) also proposed a CDMA/ TDMA based scheme for multimedia support in a self-organizing multi-hop mobile network. They introduced a network architec- ture in which the nodes are organized into non-overlapping clusters. In this method, the clusters are independently controlled and are dynamically reconfigured as the nodes move. In Richard Lin and Gerla (1997), an interference-free channel access scheduling method is proposed to handle the inter-cluster communications based on graph coloring problem. Due to the node clustering, the proposed method provides spatial reuse of the bandwidth. Furthermore, the bandwidth can be shared or reserved in a controlled fashion in each cluster. Yang and Chang (2003) proposed a dynamic code assignment algorithm for hybrid Multi-Code CDMA/TDMA systems. The proposed code assignment scheme takes into account the time-varying traffic characteristics of the mobile users. In this algorithm, the base station assigns more codes to the mobiles during the congestion period. The extra codes are then released when the congestion subsides. In this method, the congestion is predicted based on the queue length of the mobiles.

In this approach, the TDMA scheme is overlaid on top of the CDMA scheme to divide the bandwidth into smaller chunks. Hybrid-DCA forms the channel as a particular time slot of a particular code. It borrows the color-based cluster formation algorithm proposed in Hou and Tsai (2002) for clustering the wireless ad hoc networks. It also uses the channel segregation-based dynamic channel assignment algorithm (CS-DCA) proposed in Akaiwa and Andoh (1993) to assign the collision-free intra-cluster channel accesses. In Hybrid- DCA, the increase in spatial reuse is achieved by GB-DCA (Fang et al., 2000) and the decrease in control overhead is achieved by CS-DCA.

The above mentioned channel assignment schemes are practical when the input traffic is fixed or a stationary process with known parameters. This paper aims at designing a dynamic frame length CDMA/TDMA scheme for clustered wireless ad hoc networks with unknown traffic parameters. In a CDMA/TDMA scheme, intra-cluster communications are scheduled by the cluster-head using a TDMA scheme, and a CDMA scheme is overlaid on the TDMA to organize the interference-free inter- cluster communications. Therefore, to design the proposed scheme, the following three important problems must be considered. Cluster formation, code assignment (in CDMA scheme), and slot assignment (in TDMA scheme) problems. In this paper, we propose three learning automata-based algorithms to solve the addressed problems. By the proposed cluster formation algorithm, the network is partitioned into a small number of clusters, each with a cluster-head and a number of cluster members. Inter-cluster connections are handled by a CDMA scheme, in which an interference-free code must be assigned to each cluster. To do so, we propose a code assignment algorithm based on the vertex coloring problem in which the neighboring clusters are refrained from choosing the same codes. Intra-cluster channel access scheduling is based on the TDMA scheme, and the cluster-heads are responsible for the collision- free slot assignments within the clusters. Thus, after each cluster is assigned a code, the cluster-head divides the code into time slots and assigns them to the cluster members. To optimally assign the time slots, we propose a dynamic frame length slot assignment algorithm in which each cluster member receives a portion of TDMA frame proportional to its traffic load. By the proposed scheme, the following advantages can be achieved. This scheme organizes the channel access in groups, and so can be effectively used in scalable multi-hop ad-hoc networks. The number of required codes decreases to at most the number of groups, and exploiting the code spatial reuse concept, it can be minimized. In each group, using the TDMA scheme, a large number of connections can be served in a time efficient manner. Through the extensive simulation experiments, the performance of the proposed CDMA/TDMA scheme is measured and compared with CS-DCA (Akaiwa and Andoh, 1993) and Hybrid-DCA (Wu, 2007a) in terms of the number of clusters, code and channel spatial reuse, blocking rate, waiting time for packet transmission, control overhead and throughput. The obtained results show that the proposed scheme outperforms the others in almost all metrics of interest, specifically, under bursty traffic conditions.

The proposed CDMA/TDMA scheme:

To design a CDMA/TDMA scheme for clustered wireless ad-hoc networks, we encounter the following three intricate problems. The first problem is dividing the network into a minimum number of non-overlapping clusters. The second problem is to assign an interference-free code to each cluster considering the concept of the maximum code spatial reuse. That is, this problem is assigning the minimum number of codes to the clusters so that no two neighboring clusters are assigned the same codes. This problem is similar to the graph (vertex) coloring problem in graph theory which is known to be NP-hard (Karp, 1972). In CDMA/TDMA networks, the TDMA scheme is used to schedule the intra-cluster communications. By this scheme, the code assigned to each cluster is divided into several time slots. The third problem we encounter is to assign a proper portion of TDMA frame to each cluster member so that the maximum number of connections can be served during a TDMA frame. Our CDMA/TDMA scheme proposes a learning automata-based solution to each of the above mentioned problems, which are described in detail below.

Learning automata-based cluster formation algorithm (LACFA):

In ad hoc networks, the network performance is significantly degraded as the network becomes larger. The theoretical analysis shows that even under the optimal circumstances, the throughput of each host rapidly declines as the network size increases. Among the solutions proposed for solving the scalability problem in ad hoc networks, network clustering has attracted a lot of attention. The main idea behind the clustering approach is to group together the network hosts that are in physical proximity. The clusters provide a hierarchical structure to abstract the large scale networks which can be simply and locally organized . A clustering algorithm is a method for dividing the network into clusters so that each cluster includes a number of cluster members and a cluster-head (CH) with which the members can directly communicate. Due to the host mobility, strict resource limitations (e.g., bandwidth and power limitations), and hard to predict topology changes, clustering in ad hoc networks aims at dividing the network hosts into a minimum number of groups with the maximum stability.

LACFA is a fully distributed algorithm in which each host chooses its cluster-head based solely on the local information received from its neighboring hosts. LACFA is independently run at each host, and the information upon which the CH selection decision is based is confined to the neighborhood of the host. Furthermore, in the proposed algorithm, the hosts need not to be synchronized, and the neighboring hosts locally form the clusters.

Algorithm LACFA

1: **Repeat**
// Cluster-Head Selection //
2: Host h_i randomly chooses one of its actions according to its action probability vector
3: Host h_i declares the host corresponding to the selected action as its CH by broadcasting a *CHDEC* message to its neighbors
// Updating the Action Probability Vectors //
4: Host h_i computes the number of hosts declared as the CH by itself and its neighbors and denotes it N_i
5: **If** N_i is less than the dynamic threshold T_i **then**
// Dynamic threshold T_i is the minimum number of CHs selected by neighbors of h_i which is initially set to degree of h_i//
6: Host h_i rewards its chosen CH as described in Equation (1)
7: $T_i \leftarrow N_i$
8: **Else**
9: Host h_i penalizes its chosen CH as described in Equation (2)
10: **End if**
11: **Until** the probability with which host h_i chooses its CH is greater than a certain threshold
12: **End** algorithm

FIG: The proposed cluster formation algorithm.

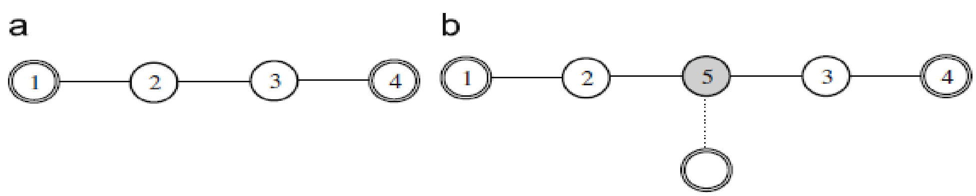

FIG: Clustering a sample network by LACFA.

The proposed cluster formation algorithm guarantees to cluster the entire network at each stage. In LACFA, each host chooses its cluster-head, and so the network is partitioned into a number of non-overlapping clusters, in which each host is only associated with a unique cluster-head. As the algorithm proceeds, the number of cluster-heads decreases as the number of members in each cluster increases. Furthermore, in the proposed cluster formation algorithm, the cluster-heads are one, two or at most three-hops away. From algorithm LACFA, it can be found that two clusters are not adjacent (or neighboring clusters), if their cluster- heads are four-hops or more away from each other. Hence, in a clustered network, some hosts have no cluster-heads, if the minimum distance between a given cluster-head and the other cluster-heads is more than three-hops. The following shows that this case does not occur in LACFA. As shown in Fig. 3(a), cluster- heads 1 and 4 are three-hops away. Let us assume that host 5 is located between hosts 2 and 3, i.e., cluster- heads 1 and 4 are four-hops away. This way, no cluster-head is associated with host 5, and this contradicts to the above assumption that in LACFA each host selects its cluster-head. On the other hand, if we suppose that host 5 is associated with a cluster-head, this cluster-head must be (at most) three-hops away from cluster-heads 1 and 4. Therefore, by LACFA, each cluster- head is at most three-hops away from (at least) another cluster head.

Learning automata-based code assignment algorithm (LACAA):

In this section, we propose a learning automata-based approximation algorithm for solving the code assignment problem in a wireless ad hoc network which is clustered by LACFA. The proposed algorithm, which we call it LACAA, aims at assigning the minimum number of interference-free codes to the clusters. Since the number of available codes is limited, it is impossible to assign a unique code to each cluster, and so we take advantage of the code spatial reuse concept in our algorithm. By this concept two or more non-neighboring clusters can be assigned the same codes. Such a code assignment problem is similar to the NP-hard vertex coloring problem in which no two neighboring clusters (or node) have the same code (or color).

The code assignment algorithm we propose in this paper is a distributed version of the first learning automata-based graph coloring algorithm proposed in Akbari Torkestani and Meybodi (2009a and 2009b). LACAA is a fully localized algorithm in which each cluster-head is assigned an interference-free code based only on the local (code assignment) information received from the cluster-head of its neighboring clusters. Like LACFA, this algorithm is independently run at each host, and the information upon which the code selection decision is based is confined to the neighborhood of the cluster.

In the proposed algorithm, each cluster-head is equipped with a learning automaton. All the cluster-heads have the same action-sets which include an action for each of the available codes. Each cluster-head randomly chooses one of the available codes (or one of its actions) according to its action probability vector. It then sends its code assignment information (i.e., the selected code) to the cluster-head of its neighboring clusters as follows.

In the networks clustered by LACFA, each CH is at most three- hops away from the other cluster-head. Therefore, in LACAA, to decide whether the selected code in interference-free or not, each host (cluster-head) is required to know the codes which are being used by at most its three-hop neighbors. For this purpose, when a CH chooses a code, it broadcasts a CSEL (i.e., code selection) message to its cluster members. Each CSEL message contains the cluster-head ID number and its selected code.

- When a cluster member receives a CSEL message from its cluster-head, it relay sit to its neighboring hosts.
- When a cluster member receives a CSEL message from the other cluster-heads, it sends the message to its cluster-head. This happens when the cluster-heads are at most two-hop neighbors.
- When a cluster member receives a CSEL message from a cluster member of the other cluster, it sends the received message to its cluster-head.
- When a cluster member receives a CSEL message from a cluster member within its own cluster, it discards the message.
- When two cluster-heads are one-hop neighbors, they directly hear the CSEL message from each other.

By this method, each cluster-head after at most three-hops receives the code assignment information of its neighboring clusters. Now, each cluster-head compare sits selected code with the codes which are being used within its neighboring clusters. If the code chosen by the cluster-head of a given cluster Is also to be chosen by the cluster-head of at least one of its neighboring clusters, cluster-head penalizes the chosen code (action) using an LR_P reinforcement scheme .Otherwise (i. e., if the chosen code is interference-free), the cluster-head compares the number of different codes selected by itself and the cluster-head of its neighboring clusters with a dynamic threshold. If it is less than the dynamic threshold, cluster-head rewards its chosen code, and penalizes it otherwise. The dynamic threshold of each cluster- head CH i (i.e., Hi) is the minimum number of codes selected by itself and the cluster-head of its neighboring clusters up to this point. This threshold is initially set to a large value, and updated to the current number of selected codes if the chosen code is rewarded. After updating the action probability vectors, each cluster-head randomly chooses an action once more, and continues this process until it chooses an interference-free code with a probability higher than a pe-specified threshold. Like LACFA, LACAA consists of a number of stages, and a sample stage of this algorithm which is run at Chi is shown in Fig.

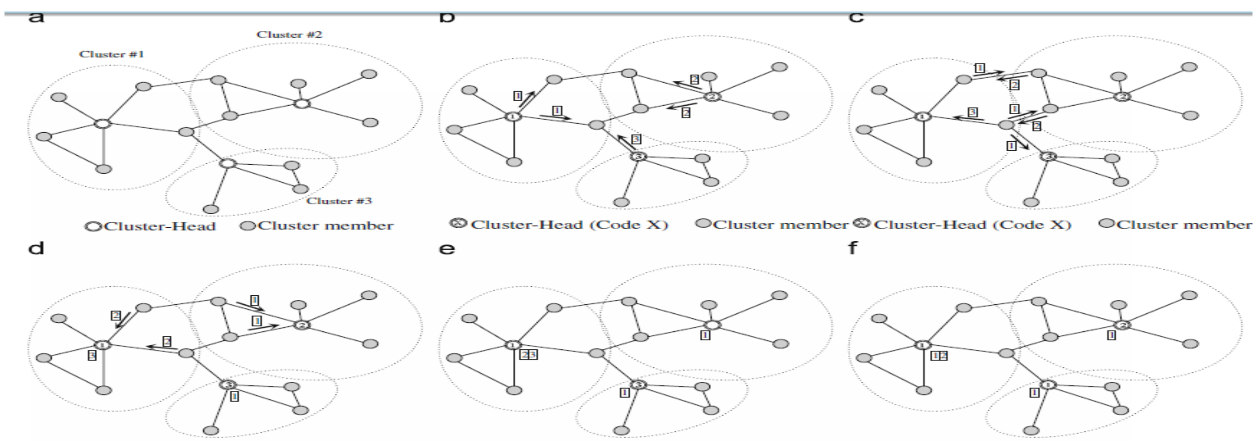

FIG. The step-by-step process of exchanging CSEL message for a sample ad-hoc network.

Learning automata-based slot assignment algorithm (LASAA):

In this section, we propose a dynamic frame length TDMA scheme called LASAA for slot assignment in wireless ad-hoc networks, where the network Is clustered by LACFA and interference-free inter-cluster communications are guaranteed by LACAA. That is, LASAA aims at optimizing the slot assignment in clustered networks, where the intra-cluster communications are scheduled by a TDMA scheme, and a CDMA scheme is over laid on the TDMA to handle interference-free inter-cluster communications. In wireless ad-hoc networks, the major resources of the network topology dynamics are the node mobility and node failure. In such networks, a host can move freely and randomly anywhere, and so it may leave its cluster and join the other at any time. Therefore, the cluster membership is highly dynamic and hard to predict due to the frequent network topology changes. In such variable-size clusters, using the basic TDMA scheme with a fixed length TDMA frame is an in efficient method for channel access scheduling, which significantly reduces the channel utilization. On the other hand, since the input traffic characteristics of the mobile hosts are different, each host requires a fraction of the TDMA frame (or a set of time slots) proportional to its traffic load. Hence, assigning the same portion of the bandwidth to all hosts decreases the channel throughput. The aim of the dynamic frame length TDMA scheme proposed in this section is to increase the channel utilization by assigning an appropriate number of time slots to each host proportional to its traffic load where the traffic parameters are unknown, and to enhance there usability of the assigned timeslots.

In LASAA, each cluster-head is responsible for a collision-free slot assignment with in the cluster, and equipped with a (variable action-set) learning automaton. The action-set of the learning automaton assigned to a cluster-head includes an action for each of its cluster members. That is, the action-set cardinality of each cluster-head is equal to the number of its cluster members. An unused time slot, at the beginning of each TDMA frame, is reserved for the new arrived hosts to transmit control packets for requesting a slot assignment or joining to a cluster as described. Thus, no data packets are transmitted in this slot. At first, all the cluster members are chosen with the same probability, and so the TDMA frame is divided into the same parts. The cluster-head randomly chooses one of its actions according to its action probability vector. The cluster-member corresponding to the selected action is permitted to transmit its packets for a time slot by a DREQ (i.e., data request) message which is sent by the cluster-head. Now, if the selected cluster member has data packet to transmit, it replies the received DREQ message by transmitting its packets. Otherwise, if the selected cluster member has no packet to be sent, it sends a NDATA (i.e., no data packets) message to the cluster- head. If the cluster-head receives data packets, it increases the portion of TDMA frame assigned to this cluster member by rewarding the chosen action .Otherwise (i.e., if it receives NDATA message), this portion is decreased, by penalizing the selected action, when the permitted cluster member has no packet to send. By this procedure, the probability of choosing a cluster member(for packet transmission)increases in future, if it has a packet to send, and decreases otherwise .Then, cluster-head randomly chooses one of its actions again, and does the same operations as before. As the algorithm proceeds , the portion of TDMA frame assigned to each cluster member converges to the proportion of time it has a packet to transmit. By this method, the channel utilization is maximized when the bandwidth portion taken by each cluster member is proportional to its need. Fig. 6 shows the proposed algorithm which is run at cluster-head CHi.

Algorithm LASAA

Loop for ever
  Cluster-head CH_i randomly chooses one of its members
  CH_i assigns the channel to the selected member
  If the selected member has a packet to transmit **then**
    CH_i rewards the selected member as described in Equation (1)   *// Increase the bandwidth portion of the selected member //*
  Else   *//Cluster-head receives NDATA message//*
    CH_i penalizes the selected member as described in Equation (2)   *// Decrease the bandwidth portion of the selected member //*
    End if
End loop
End algorithm

The proposed dynamic frame length slot assignment algorithm.

Analysis results:

To study the performance of the proposed learning automata- based CDMA/TDMA scheme, we have conducted several simulation experiments in three groups. The first group of our simulation experiments investigates the effectiveness of the proposed cluster formation algorithm, namely LACFA. In the second group of our experiments, we compare the efficiency of the proposed code assignment algorithm, LACAA, with the similar methods. Finally, the third group of conducted experiments assesses the performance of the proposed slot assignment algorithm (i.e., LASAA) in comparison with the existing methods. In our simulation scenarios, an ad-hoc network consisting of N hosts is modeled in which the hosts are randomly and uniformly distributed within a two-dimensional simulation area of size1000m_1000 m. The number of hosts ranges from 60 to 200 with increment step of 20.IEEE 802.11is used as the MAC layer protocol, and two ray ground as the propagation model. The wireless hosts communicate through a common broadcast channel ofcapacity2Mb/s using omni directional antennas. Each host is modeled as an infinite-buffer, store-and-forward queuing station. The radius of transmission range of all hosts is set to be the same, which is 250m through out the simulation process. TDMA frame is subdivided into 30 equal length transmission time slots. The first slot of each TDMA frame is reserved for the control packets, and the remaining slots are data channels. Each simulation experiment is executed for 1000s.At each host, the arrival of the new connections is Poisson distributed with arrival rates of 5,10 ,15, and20 connections/min. Each host has a particular traffic load which is defined by randomly choosing from the above mentioned arrival rates at the beginning of each simulation. The duration of the connections is assumed to be exponentially distributed with mean 0.2.The simulation results shown in this paper are averaged over 50 runs. In our experiments, we compare the results of the proposed algorithms with their counter parts of CS-DCA which is a channel segregation- based channel assignment method proposed by Akaiwa and Andoh (1993), and Hybrid-DCA which is a dynamic channel assignment strategy proposed for clustered wireless ad-hoc networks by Wu (2007a).

In these experiments, the performance of the above mentioned algorithms is evaluated in terms of the following metrics of interest:

- ***Number of clusters*****:** It is defined as the number of non- overlapping groups (clusters) into which the network is partitioned. This metric is recommended for evaluating the efficiency of the proposed cluster formation algorithm.
- ***Code spatial reuse*****:** This metric is defined as the average number of times a code can be used. That is, code spatial reuse is the average number of clusters which are assigned the same code. This metric is used to assess the performance of the code assignment algorithm (LACAA).
- ***Number of used codes*****:** It is defined as the number of codes which are assigned to the clusters. This metric is inversely proportional to the code spatial reuse.
- ***Blocking rate*****:** It is defined as the ratio of the number of the blocked connections to the total number of requested connections. This metric can be divided into two categories .Blocking rate due to no code, and blocking rate due to no slot. The first defines the rate of connections blocked due to the lack of available codes, and the second defines the rate of blocked connections due to the lack of free slots.
- ***Waiting time for packet transmission:*** This metric is defined as the average time each packet has to wait in the queue before transmission. This is the time

between the arrival and transmission for each packet.

- ***Channel spatial reuse***: This metric is used to estimate the efficiency of the proposed slot assignment algorithm(LASAA) and defined as the average number of hosts which use the same channel.
- ***Throughput***: This metric is defined as the ratio of the average number of packets transmitted per slot to the total number of packets received. The traffic load of the various hosts is different in realistic scenarios, so this metric can be optimized by LASAA in which the bandwidth portion (number of slots) assigned to each host Is proportional to its traffic load.
- ***Control overhead***: It is defined as the number of extra (control) messages required for channel assignment.

Conclusion:

In this paper, we designed adaptive learning automata- based CDMA/TDMA scheme for clustered wireless ad hoc networks, in which the collision-free intra-cluster communications were organized by the cluster-heads using a TDMA scheme, and the interference-free inter-cluster communications using the CDMA scheme. To design this scheme, we proposed three learning automata-based algorithms for cluster formation (LACFA),code assignment (LACAA)and slot assignment (LASAA),respectively. In this scheme, by LACFA, the wireless hosts were first grouped into a minimum number of non-overlapping clusters. Then, by LACAA, an interference-free code was assigned to each cluster. Finally, by the proposed dynamic frame length slot assignment algorithm, LASAA, each cluster member was assigned a fraction of TDMA frame proportional to its traffic load. Extensive simulation results showed that the proposed CDMA/TDMA scheme out performs the existing methods for almost all metrics of interest, specifically, under bursty traffic conditions.

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