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여 재 현

An Efficient Code Assignment Algorithm in Wireless Mesh Networks

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Abstract

Wireless Mesh Networks (WMNs) have emerged as one of the new hot topics in wireless communications. WMNs have been suggested for use in situations in which some or all of the users are mobile or are located in inaccessible environments. Unconstrained transmission in a WMN may lead to the time overlap of two or more packet receptions, called collisions or interferences, resulting in damaged useless packets at the destination. There are two types of collisions; primary collision, due to the transmission of the stations which can hear each other, and hidden terminal collision, when stations outside the hearing range of each other transmit to the same receiving stations. For a WMN, direct collisions can be minimized by short propagation and carrier sense times. Thus, in this paper we only consider hidden terminal collision while neglecting direct collisions.

To reduce or eliminate hidden terminal collision, code division multiple access (CDMA) protocols have been introduced. The collision-free property is guaranteed by the use of spread spectrum communication techniques and the proper assignment of orthogonal codes. Such codes share the fixed channel capacity allocated to the network in the design stage. Thus, it is very important to minimize the number of codes while achieving a proper transmission quality level in CDMA WMNs. In this paper, an efficient heuristic code assignment algorithm for eliminating hidden terminal collision in CDMA WMNs with general topology.

Keywords : Wireless Mesh Networks, Multi-hop, Code Assignment

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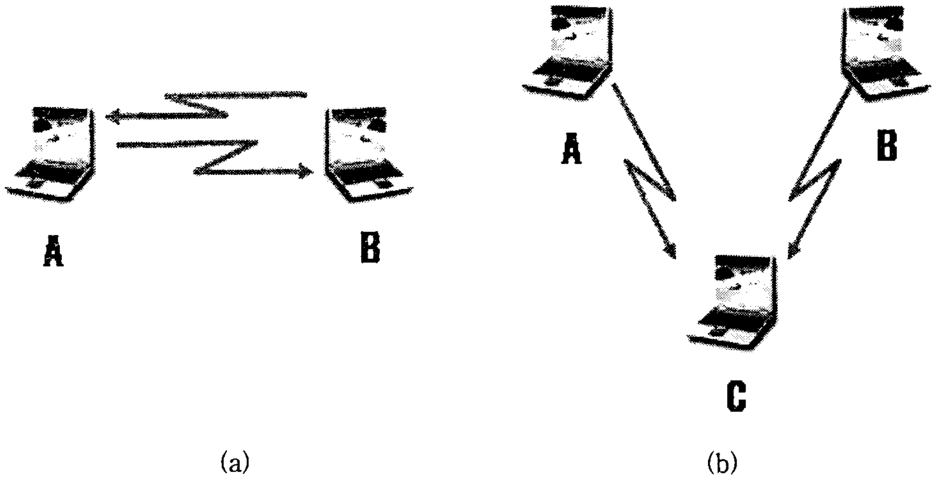
1. Introduction

The need to let remote computers exchange multimedia data in any time any where led to the design and development of the currently ubiquitous telecommunication networks. The first computer network consisted of computers connected by point to point lines, which were usually telephone lines. This arrangement is not suitable, and in certain cases infeasible, for mobile computers, or computers displaced in wild areas where the telephone system is underdeveloped or not present at all. To support ubiquitous and mobile computing, wireless communication media are needed such as radio frequencies. The rapid development of this area has been greatly stimulated by the need to provide computer network access to mobile terminals and computer communications in the mobile environment.

Computers linked by radio frequencies are equipped with radio transmitters and receivers (transceivers) whose task is to broadcast outgoing packets and to listen for incoming packets. The arrangement of computer and transceiver is often called station. Sometimes all the stations can directly receive each other's transmissions. In this case, the network is called a one-hop, and is typical for fixed and relative close stations, or for stations communicating by a satellite. More often a packet must be received and later retransmitted by intermediate stations before reaching its final destination; the network is then multi-hop. This multi-hop type of wireless computer networks is called Wireless Mesh Networks (WMNs). WMNs have been suggested for use in situations in which some or all of the users are mobile or are located in inaccessible environments. One of useful applications of WMNs is that long-distance mesh network using IEEE 802.11 (WiFi) [Brewer, 2005]. It can provide low-cost broadband Internet access to remote rural locations. WMN can also provide self-organized ad-hoc wireless network to access IP-based services in wide areas. Various topics on WMNs have been researched such as routing, resource scheduling, and so on [Raniwala et al., 2004; Alicherry et al., 2005].

In order to provide wireless data communication service, WMNs must include a channel access protocol whose role is to allow nodes to multiplex their traffic on the shared channel. In addition, the access protocol must include management functions that track all users and route data reliably in spite of possible topological changes. The main difficulties in the design of packet radio networks stem from the unique features of this type of networks, namely, the multi-hop shared channel where not all users are within direct radio connectivity of each other, and the dynamic network topology due to mobility of nodes.

Unconstrained transmission in a WMNs may lead to the time overlap of two or more packet receptions, called collisions or interference, resulting in damaged useless packets at the destination. Collided packets must be retransmitted, thus increasing the delay and the bandwidth usage, which in turn lowers the system throughput. There are two types of colli-



〈Figure 1〉 Collisions : (a) Primary Collision (b) Hidden Terminal Collision

sions; direct (or primary) collision, due to the transmission of the stations which can hear each other, and hidden terminal (or secondary) collision, when stations outside the hearing range of each other transmit to the same receiving stations.

In <Figure 1(a)>, stations A and B are within the transmission range of one another. In this case if A and B start transmission at the same time, then packets from both stations will be expected to collide. We refer to this as the primary collision. In <Figure 1(b)>, stations A and B are not within the transmission range of one another, but there is a third station C which is within the transmission range of both A and B. In this case if A and B start simultaneous transmissions then C will not be expected to receive from both A and B at the same time. We refer to this as the hidden terminal collision. In order to guarantee the packet transmission without any collisions (collision-free), the next two constraints must be satisfied.

1) A station cannot have transmission and reception status simultaneously.
2) A station is not allowed to receive two or more transmissions simultaneously.

In WMN, it is well known that the primary collision can be minimized by short propagation and carrier sense times. Thus, in this paper the hidden terminal collision is only considered while neglecting the primary collision. To reduce or eliminate the hidden terminal collision, code division multiple access (CDMA) protocols have been introduced [Cidon et al., 1989; Hu, 1993; Prohazka, 1989]. CDMA code assignments in a WMN can be performed as the following two schemes : receiver oriented code assignment (ROCA) scheme and transmitter oriented code assignment (TOCA) scheme. When the transmitters are code-agile, namely, able to communicate over several codes, we are in the presence of a ROCA scheme. Alternatively, the receivers are code-agile, in which case the scheme is a TOCA.

ROCA schemes are cheaper and simpler, but yield a lower throughput than TOCA ones. Moreover, the hidden terminal collision cannot be completely avoided by ROCA schemes, while they can be totally eliminated by properly assigning orthogonal codes in TOCA schemes [Makansi, 1987]. In other words, TOCA schemes allow a collision-free packet transmission. The use of spread spectrum communication techniques and the proper assignment of orthogonal codes guarantee the collision free property. Such codes share the fixed channel capacity allocated to the network in the design stage. Thus, it is very important to minimize the number of codes while achieving a proper transmission quality level in a CDMA WMNs. In this paper, an efficient heuristic algorithm is suggested to minimize the number of codes needed for eliminating hidden terminal collision in a WMN and is assessed by making comparison to naive greedy graph coloring heuristic paradigm.

2. Problem Description and Modeling

A WMN can be modeled as an undirected graph $G=(V, E)$, where the set of vertices $V=\{1,\cdots,n\}$ represents the set of stations, and the set of edges E the common channel property between pairs of stations. More precisely, there is a one-to-one mapping of the stations onto the vertices in V, and two vertices i and j in V are joined by an undirected edge $(i, j) \in E$ if and only if their corresponding stations can hear each other's transmission. In such a case, the vertices (or, equivalently, the stations) are called adjacent. Thus, a graph G represents a network topology. A path between the vertices i and j is a sequence $i=v_1, v_2, \cdots, v_k=j$ of vertices such that $(v_k, v_{k+1}) \in E$ for $k=1,2,\cdots,h-1$, and its length is $h-1$, namely the number of edges appearing in it. The distance d_{ij} between two vertices i and j of G is the length of the shortest path between i and j, that is, it equals the minimum number of hops that a packet must undergo in a communication between stations i and j. Two vertices (stations) i and j can generate a hidden terminal collision if and only if they are two hops away, namely, when $d_{ij}=2$. Such an collision can be eliminated if i and j transmit on different orthogonal codes. Thus, the code assignment problem for hidden terminal collision avoidance (CAP) can be described as follows :

(CAP)
Assign codes to stations so that every pair of stations at distance two is assigned a couple of different codes and the minimum number of different codes is used.

In special cases, optimal code assignment can be found quickly. It has shown that the minimum number of codes needed to eliminate the hidden terminal collision cannot be smaller than the maximum number of vertices which are mutually at distance 2 [Makansi, 1987]. This statement allowed him to derive optimal code assignments for some special kinds of regular network topology, such as busses, hexagonal, and grid topology. Using the same method in [Makansi, 1987], the authors in [Bertossi et al., 1995] derived optimal code assignments for two other regular network topology, namely, rings and trees.

However, no polynomial time algorithm exists which guarantee to always produce an optimal code assignment for general network topology. By equating codes with colors, the problem can be graph-theoretically formulated as that of coloring the vertices of the graph with the minimum number of colors in such a way that the vertices at distance two are colored with different colors. The above problem is a variation of the classical vertex coloring problem, where vertices at distance one have to be assigned different colors, which is known to be strong NP-complete [Karp, 1972]. Hence, in this paper, we will propose an efficient code assignment algorithm with hidden terminal collision avoidance for general network topology.

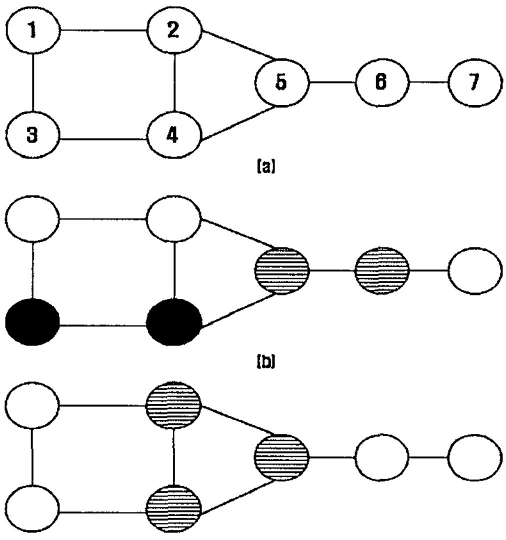
3. Centralized Algorithm

3.1 Basic Algorithm

Basic code assignment algorithms are based on a naive greedy graph coloring heuristic paradigm [Makansi, 1987; Bertossi et al., 1995]. The algorithms in [Makansi, 1987] is based on a naive greedy graph coloring heuristic paradigm as follows :

Let the n stations be named $1, 2, \cdots, n$ according to any specified criterion. Moreover, let $H2(i)$ be the set of stations j which are at distance 2 (that is, two hops away) from station i and such that $j < i$, for $i = 1, 2, \cdots, n$. The algorithm considers the stations $1, 2, \cdots, n$ sequentially, one at a time, and assigns code k to station i if it is the smallest index code not assigned the stations in $H2(i)$. Repeat until all the stations are assigned.

As an example, consider the seven station network depicted in <Figure 2(a)>. The code assignment found by the above algorithm is that exhibited in <Figure 2(b)>. Such an assignment uses 3 codes, and is not optimal, since an assignment using only 2 codes exists, as shown in <Figure 2(c)>. The optimal code assignment for this example would be found by the algorithm if the stations are renumbered in such a way that the number of station 2 and 3 were swapped.



<Figure 2> Example of Code Assignment : (a) A network with seven stations (b) Code assignment by algorithm in [Makansi, 1987] (c) Optimal code assignment

The new part of [Bertossi et al., 1995] is the node ordering, and the choice of the best ordering. In [Bertossi et al., 1995], they ran five variants of the algorithm on random networks in order to find the best ordering criterion. Each variant differs from the others according to the chosen criterion for ordering the station number. The considered ordering criteria were : random ordering (RANDOM), increasing number of neighbors at distance two (D2 increasing), decreasing number of neighbors at distance two (D2 decreasing), increasing number of neighbors at distance one (D1 increasing), decreasing number of neighbors at distance one (D1 decreasing). The random ordering algorithm is identical to Makansi's algorithm. The lower number of codes was achieved by the D2 decreasing criterion.

3.2 A New Algorithm

The basic algorithms in previous section are very simple and easy to implement but do not find the minimum number of codes. In point of view of graph theory, the basic algorithms are considered as variations of the sequential vertex coloring algorithm, which is well known method in graph theory [Christofides, 1975]. It is also known that, in the classical vertex coloring problem, the best ordering criterion is the decreasing order of neighbors at distance one. Hence it is obvious that the best criterion for the CAP is D2 decreasing. There are many heuristic procedures for the classical vertex coloring problem which can achieve good solutions and have polynomial time complexity.

In order to design a new efficient algorithm, the concept of saturation degree is applied to the proposed algorithm in this section. The saturation degree of an unassigned station of CAP can be defined as the number of different codes which are assigned to its two-hop neighboring stations.

In order to avoid hidden terminal collision, every pair of stations at distance two is assigned a couple of different codes. So, it is quite obvious that the station with the largest number of neighbors at distance two (*MAXD2* station) must be assigned the code first, which is supported by [Bertossi et al., 1995]. However, the previous algorithms ignored the assignments for two-hop away neighbors of the *MAXD2* station. Once the *MAXD2* station has been assigned a code, it would be more efficient to assign the least possible (lowest numbered) code to a station with a maximal saturation degree. This is because we know that they must have code different from the one assigned to the *MAXD2* station. The main idea of our algorithm is to assign codes to the station with maximal saturation degree just after the assignment for the *MAXD2* station. It can resolve the constraint that every pair of stations at distance two is assigned a couple of different codes more efficiently. The detailed algorithm, named as Saturation Degree (SatD) Algorithm, is described as follows :

(Saturation Degree Algorithm)

Let *MAXD2* be the station with the largest number of neighbors at distance two.

(Step 1) : Find *MAXD2* station among stations which do not have a code and assign the code 1 to $MAXD2$.

(Step 2) : Choose a station with a maximal saturation degree and assign the least possible (lowest numbered) code.

(Step 3) : If all the stations are assigned then STOP, else Go to(Step 2).

In the case of the network in <Figure 2>, SatD algorithm can find the optimal code assignment as in <Figure 2(c)>. First, assign the code 1 to the $MAXD2$ station, node 1, and then the node with a maximal saturation degree is the node 4. and assign the code 2 to the node 4. And then $MAXD2$ stations can be selected sequentially as node 5, 3, 2, 6, 7, and it can be easily found that the number of codes be assigned is 2.

Moreover it is known that the saturation degree algorithm in the classical vertex coloring problem is exact for bipartite graphs. That is, for bipartite graphs, the saturation degree algorithm can find optimal solutions [Brelaz, 1979]. For a given graph G, we define a new graph G_{ref} which is reformed by the same set of station V with all links removed and a link is added between each pair of stations which share at least one common neighbor. The importance of G_{ref} is that a legal one-hop coloring of G_{ref} implies a legal CAP solution to the original graph G. If a WMN can be reformed to a bipartite graph using the proposed graph reformation method, the proposed algorithm in this section can achieve an optimal code assignment for CAP.

4. Simulation results

As described in the previous section, SatD algorithm can find optimal solutions in special network topology. However in general network topology, it is not possible to prove that our algorithm is more efficient in all cases because CAP is strong NP-complete. Hence, in order to show that our algorithm is more efficient in general network topology, we ran our algorithm on finite random networks with varying connectivity patterns and number of stations. We considered n station networks, with five different values 20, 40, 60, 80, and 100. The stations were represented by n randomly generated points in the unit square $[0, 100] \times [0, 100]$. Each point was generated as a pair of random integer numbers ranging between 0 and 100. For a given set of n points, the edges of the networks were chosen among all pairs of points whose Euclidean distance was not larger than r. We considered four values of r, namely 20, 40, 60, and 80. Hence we considered $5 \times 4 = 20$ cases. For each case, 500 networks have been generated and tested. The results are shown in <Table 1>. AVG_OLD and AVG_NEW are the average numbers of codes needed by the basic algorithm in section 3.1 and the algorithm proposed in this paper, respectively. In all 20 cases, our algorithm requires a smaller number of codes than the basic algorithm. In <Table 1>, BETTER is the number of networks out of 500 networks in which our algorithm works better than the basic algorithm and WORSE is the number of networks in which our algorithm works worse than the basic algorithm.

〈Table 1〉 Simulation Results

		r = 20	r = 40	r = 60	r = 80
n = 20	AVG_OLD	3.208	4.324	4.752	2.582
	AVG_SatD	3.208	3.668	3.876	2.582
	BETTER	0	500	438	0
	WORSE	0	0	0	0
n = 40	AVG_OLD	3.93	5.8	4.492	3.438
	AVG_SatD	3.93	5.634	4.286	3.244
	BETTER	0	358	448	266
	WORSE	0	0	29	0
n = 60	AVG_OLD	5.138	6.892	4.946	3.8
	AVG_SatD	5.114	6.802	4.712	3.684
	BETTER	292	497	474	408
	WORSE	199	1	24	89
n = 80	AVG_OLD	6.056	7.716	5.382	3.946
	AVG_SatD	6.054	7.686	4.79	3.884
	BETTER	378	379	486	453
	WORSE	84	120	10	0
n = 100	AVG_OLD	6.852	8.236	5.588	4.156
	AVG_SatD	6.84	8.108	5.094	4.102
	BETTER	377	491	499	494
	WORSE	113	8	0	3

n : the number of stations.
r : if Euclidean distance between two stations is less than r, an edge is established.
AVG_OLD : the average number of codes over 500 cases by the basic algorithm.
AVG_SatD : the average number of codes over 500 cases by the proposed algorithm in this paper.
BETTER(WORSE) : the number of networks out of 500 networks in which our algorithm works better(worse) than the basic algorithm.

5. Conclusion

In order to solve the code assignment problem for hidden terminal collision avoidance, we propose an efficient algorithm based on the degree saturation method, which is a well-known one in graph theory. We tested our algorithm on randomly generated networks and compare the results with the basic algorithm in the classical vertex coloring problem. The results show that our algorithm can find the better solutions in all cases. In addition, our algorithm has a good property that it can find optimal solutions when a network can be reformed to a bipartite network using the reformation method in section 3.2.

Wireless communication has become an important field of activity in telecommunications. The demand for services increases dramatically and the required service is no longer restricted to the telephone call. The emerging wireless data communication services, such as mobile computing, mobile multimedia, etc., play an increasingly important role in current wireless systems. In wireless data communication networks, sharing of spectrum (bandwidth) is essential because spectrum is not only expensive but also inherently limited. Thus, an important consideration in the design of a wireless system is the multiple access protocol.

This paper has considered a CDMA protocols in WMNs and has introduced the broadcast scheduling problem, which is finding an optimal schedule that guarantees the collision-free transmission. This paper also has proposed the algorithms and the simulation results have shown that the proposed method provides good performances. Another important issue in WMNs is to design efficient routing protocols. As a network becomes larger and the number of mobiles increases, it must have an optimal routing algorithm. This can be a good further research work.

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■ 저자소개

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