Bandwidth Routing in Multi-hop Packet Radio Environment

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Abstract

In this paper, we propose a bandwidth routing algorithm in a multi-hop packet radio environment, which is not necessarily a cellular structure network and could have no fixed base stations. Each mobile station has the responsibility to transfer packets for others. The wireless network can be either stand-alone, or connected to the wired network such as ATM. To emulate cellular structure, we divide all the mobile stations into clusters. Bandwidth calculation is based on a reservation-TDMA scheme and the clustering structure. In this algorithm, every mobile station builds a routing table for every possible destined station, with knowledge of bandwidth information for each recorded path. The key issue in path bandwidth calculation in this multihop wireless environment is that the bandwidth of a path consisting of several links, is not simply the minimum bandwidth of these links. Additional consideration on the common free slots of these links may decrease the path bandwidth. By this more precise calculation, the packet loss rate can be very low and the call dropping rate is controlled. This is very important for the connection quality to be guaranteed and thus makes the QoS routing possible for real time traffic in local multi-hop packet radio environment. It also makes this environment compatible with the wired network, such as ATM.

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1 、 Introduction

The multimedia data transmission technology has been developed maturely in wired network. However, in the recent cellular wireless networks only transmission of voice applications is the main focus. CDPD (Cellular Digital Packet Data)[1] protocol is therefore developed to extend the multimedia capability to the existing cellular networks. The routing algorithm in the cellular networks can be divided into wireless part and wired part. The wireless part is simple, since the mobile station just need to send packets directly to the local base station in one hop. The packets then will go through the wired backbone network to the destined base station, which will transfer the packets to the destined station. The key routing issue here for wired part is how to transport multimedia traffic, especially those delay-bounded or real-time packets, with certain guaranteed quality of service (QoS) requirements. How to choose a route that can support traffic QoS requirements is a main feature to such a multimedia network. There are many literatures in this category : [4] and [5] are for Internet, [6] and [13] are for ATM wireline backbone. On the other hand we are considering some situations in which non-cellular multi-hop packet radio environment is more suitable. The first case is in the war field, it's obviously hard to communicate in wired or cellular wireless network because the violent fire will cause fixed equipment damaged. The second situation is in sparsely populated areas or far away land, the cost to construct wired or cellular wireless network will be out of proportion to the utilization. Because the traffic payload will not be too heavy and most of the packets are just for local communication. The third case is on campus or in a building, it's also not cost effective to install permanent base station in this small area for local communication. As two mobile users who are both on the campus need to communicate peer to peer, the data packet can be transferred by the mobile stations between them.

The network with this kind of environment can also be connected to wired infrastructure, or just be a stand alone one. In the former situation, it can recover from failure of base stations in wireless cellular-based networks. As shown in figure 1.1, when the wired base station B fails, the connection can be recovered by multi-hop routing, that the intermediate mobile station(s) will transfer the packets for the connection. Other scenarios may also apply. For example, when one mobile is too far away from any base stations, it can use this technique of multi-hop routing to ask for its idle neighbor mobile to forward the packets, etc.

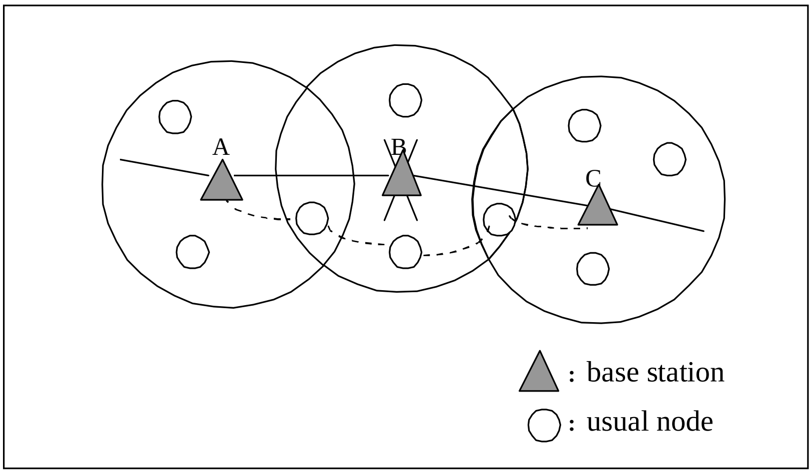

Figure1.1: Cellular based network failure & multi-hop routing

The main application we consider here for this kind of either stand alone network, or being connected to a wired infrastructure, is multimedia. Then, in addition to medium access control, the packet routing over the wireless network will need to support the required QoS for real time traffic. Among the elements of QoS, such as delay, bandwidth, signal quality, etc , bandwidth is the most important to performance. More precisely, the main goal of this paper is to understand how the knowledge of network bandwidth can assist mobile computing, including how the information can be efficiently collected and how the applications can exploit this information in order to enhance performance and to support QoS in a mobile environment. Previous work for packet radio routing, has not yet fully considered this multimedia service. Duct routing [2] in DARPA Packet Radio was first proposed to try to support voice transmission in a multihop wireless network. It turned out to waste too much bandwidth since many duplicates of voice packets would exist in the network while topology changed. Other recent routing algorithms, [3], which proposed a distributed routing algorithm for mobile wireless networks, in general did not utilize the concept of bandwidth reservation like in ATM to enhance the real time traffic throughput in the wireless network environment. In other words, they won’t support QoS. In this paper, we propose our bandwidth routing idea that considers not only the medium access scheme which most affects throughput in packet radio, but also the advantage of cellular architecture.

Frequency reuse is one of the important features of cellular structure in the wireless environment. This feature improves utilization of limited bandwidth. From figure 1.2, connection AB and connection CD could exist at the same time, if they are in different cells of the cellular model or in wired networks. Otherwise they would interfere with each other, if they are in the same cell or in the non-cellular packet radio environment. To maintain the feature, frequency reuse, we adopted a clustering algorithm [7] to emulate cellular structure of wireless network in this paper, which will divide all the mobile stations into clusters. Inside each cluster, reservation-TDMA is used in order to guarantee required QoS for real time traffic. Thus, the notion of "bandwidth" for a certain link is equal to the number of free TDMA slots on the link.

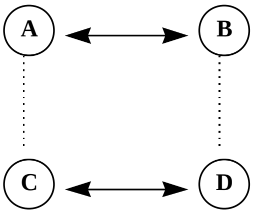

Figure1.2: Connection in different environment

If node A knows the path to node B and available bandwidth of this path when it wants to communicate with node B, then it could estimate if the connection would be set up with enough bandwidth. There are many routing algorithms in the literature, such as [8] [9]. Among these, the modified B-F family is most suitable for our case, since it is simple. We just chose one of those, DSDV[8], as our first starting point. We combine bandwidth calculation and DSDV routing algorithm into a new one. Bandwidth calculation is the important issue in this paper, which is similar to the parameter QoS in ATM for real time traffic connection. To get bandwidth information in TDMA scheme, each mobile node broadcasts its own time slot condition to neighbors and then transfers this kind of message it received. With this information, the mobile node can do bandwidth calculation and build a routing table for any destined mobile node.

2 、 Problem Description

It surely has many problems in the multi-hop packet radio environment, such as the interference from noise with data signals, higher error rate, connection handover, power control, channel shadowing, etc. In this paper, we focus our study on bandwidth routing, which includes bandwidth reservation, bandwidth calculation without clustering and path selection. We will discuss these issues respectively later in this article. Let's consider the example in figure 2.1, the lines indicate the connectivity of the five nodes. When node A sends message to node B in time slots 1 and 2, node C will receive it, too. Because nodes cannot receive and transmit packet at the same time (due to peer to peer communication capability, the same frequency band is used for both transmitter and receiver), node C cannot send or receive message concurrently from any other node in the time slot 1 or 2, which should be reserved for connection AB. Otherwise it will cause collision with the data packets from node A. Similarly node C has to broadcast the reservation , in order that node D can know this situation. When node D wants to send messages to node C, it will choose time slots from the remaining unreserved slot pool, say slot 4 and 5. Node B, in turn, will do the reservation for connection CD. The time slots in figure 2.1 which are marked with "R" indicate that the slots had been reserved directly for itself or the neighbors, and those marked with "X" indicate that they had been reserved indirectly for some special neighbors. Node D can also communicate with node E in time slots {1,2}, where node E could be a neighbor of node D but not of node A. This is the typically same situation as the well known hidden terminal problem [10]. We will show how we avoid this problem for bandwidth calculation in the next section.

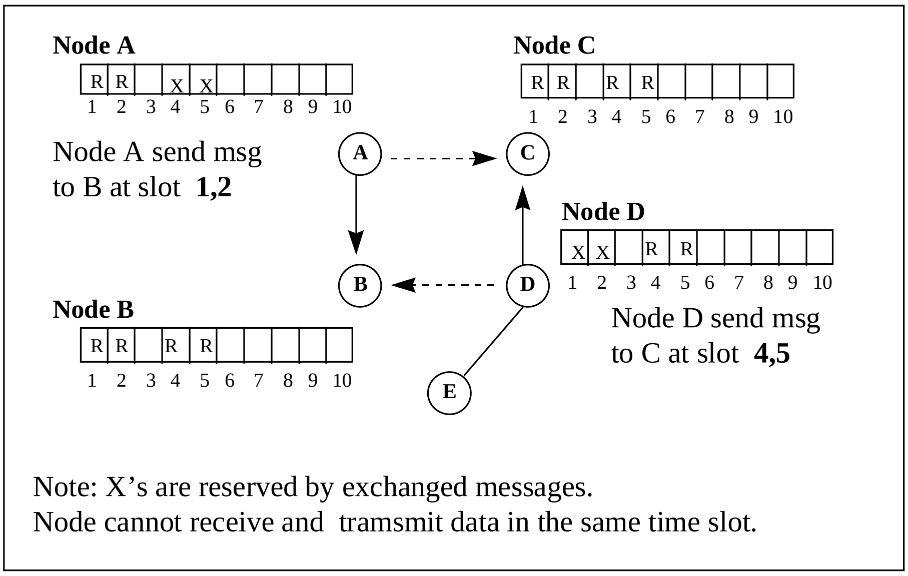

Figure 2.1: Bandwidth Reservation at neighbors and non-neighbors in TDMA

We had depressed packet interference between the mobile nodes by every node's reserving bandwidth for its neighbors. Opposed to intuition, bandwidth calculation turns out to be much more complicated in a wireless environment than in a wired one. For example in figure 2.2, it is assumed that the time slot conditions for the four nodes are shown as in the right side. A frame cycle has ten time slots and those time slots marked with F tell that they are absolutely free, not reserved for any neighbors or used by itself. Node C and node D are one hop away, node B and node D are two hops away, and so on. From the time slot conditions, we know that node C and node D have three common free slots {1,2,5}, i.e. BW(CD)=3. Node B and node C also have three common free slots, again BW(BC)=3, and so on. If it is in the wired environment, bandwidth calculation is much simpler. It can be shown : BW(AD) = Min (BW(AB), BW(BC), BW(CD)). Thus we will get BW(AD) = 2 in the wired environment. But bandwidth calculation in the wireless environment is not as simple as in the wired environment. For the same example in figure 2.2, BW(BD) would be 2 instead of 3 as in the wired environment. It is because time slots 1 and 2 have appeared in both the common free slots of both link BC and link CD. Recall the restriction that node C cannot receive packets from node B and transfer them to node D concurrently. If time slot 1 of node C is used in connection BC, then slot 2 can be used in connection CD, and vice versa. The first problem is how node B knows that it can only use one slot of the slot set {1,2}for connection

BC, and reserves the other one for connection CD. The second is how node B knows which time slots are also in the common free slot set for node C and D. To solve these problems, the nodes have to exchange some messages with each other. We leave the solutions in the third section of this paper.

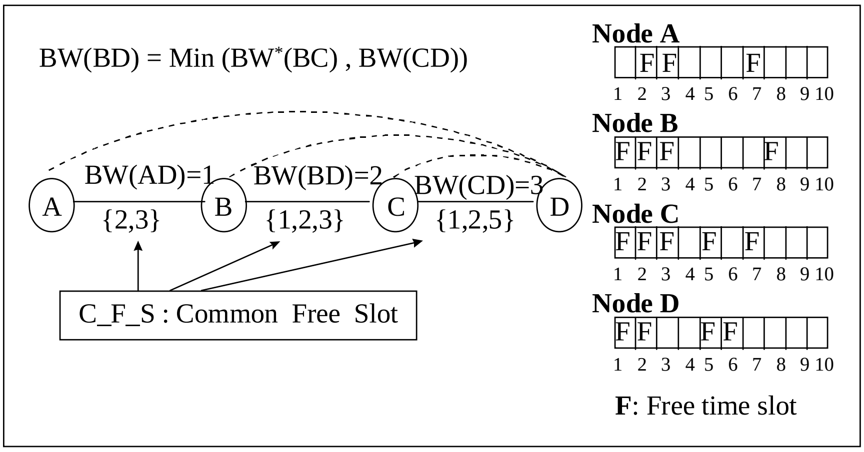

Figure 2.2: Exchange bw_msg with each other

The third problem is the routing path in the wireless multi-hop packet radio environment. The topology of the nodes changes dynamically because of the mobility of stations. This feature leads to the frail connection. That is, the virtual connection could failed at any time due to movement of the intermediate stations and thus could result in unreliable service. Also the time required to set up a new VC may be too long to be tolerant for real time connections. To reduce the probability of call dropping caused by handover re-routing, we have to prepare some stand by paths at the same time while we build up the routing tables. Whenever the node find that the original path is not useful, it can switch to a stand by path immediately.

3 、 Solution

To solve the problems of bandwidth routing in the multi-hop packet radio environment, we proposed an algorithm based on the loop free DSDV routing algorithm and TDMA mechanism. That is, time is segmented into frame cycles, and each frame cycle consists of control phase and transmit phase, as shown in figure 3.1. Nodes broadcast their slot conditions in control phase, and transmit their real data in transmit phase.

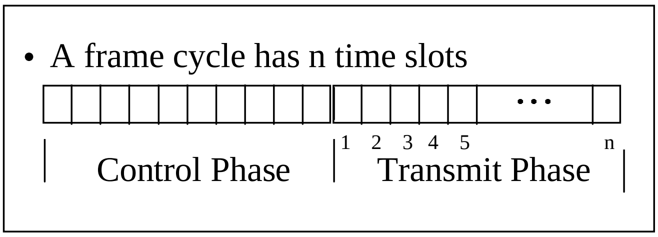

Figure 3.1 : A frame cycle in TDMA mechanism

This algorithm will find some candidate paths (shortest + standby) to any destination with associated available bandwidth. Each node will choose the shortest path with enough bandwidth when it wants to call the desired destination. If no proper path is available, the call would be rejected. This section first describes how this algorithm divides the nodes by their position and id number into clusters. Nodes in the same cluster are in the same frequency band. Second, it describes how each node does bandwidth calculation in the clustered network. Third, it describes how each node establishes its bandwidth routing table for any destination.

3.1 Clustering

To take advantage of frequency reuse property, we emulate cellular structure by clustering all the mobile stations into different channels [11]. To do the clustering, every node has to broadcast "clustering" message. Two nodes in the same cluster at this moment may depart at next moment because of mobility. This clustering algorithm in the control phase of every frame cycle overcomes the change of topology. In figure 3.2, it shows the initial connective topology of ten nodes.

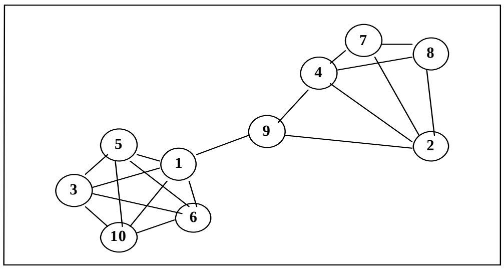

Figure 3.2 Topology of a multi-hop wireless network

In control phase, each node has to broadcast "clustering" message which contains its id number to its neighbors. If the node's id is the smallest among its neighbors, it will be selected as a cluster head. Once a node becomes a cluster head, all its neighbor nodes will belong to the same cluster. Figure 3.3 shows the clustering result from figure 3.2

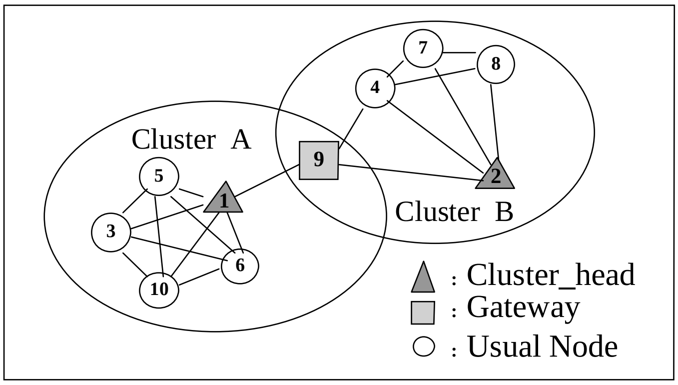

Figure 3.3: Clustered multi-hop wireless network: emulating the cellular structure

The nodes in the same cluster use the same channel. Different clusters use different channels. Each node in Cluster A can make direct connection with the cluster head node 1, but not any two nodes in the same cluster can also make direct connection, they may be two hops away. A node which can make two (or above) direct connections to cluster heads is the bridge over the two (or above) clusters, such as node 9 in figure 3.2. We say it plays the role of gateway. That is, the packets involved with any two nodes in different clusters must be transferred by the gateway over the different channels. The packets involved with two nodes that are in the same channel but two hops away should be transferred by their common neighbors.

3.2 Bandwidth Calculation for Clustered Networks

To do bandwidth calculation, every node has to broadcast its own slot condition. When a node receives slot conditions from neighbors, it first does bandwidth calculation. Then it will do some proper modification on the slot conditions according to its own and transfers it with the calculation result. If the routing table has no more space to store this information or the result of bandwidth calculation is not better than the existing ones, then the received message will stop its traveling in this multi-hop packet radio network. This feature prevents the message from traveling in this multi-hop packet radio network endlessly and from wasting valuable bandwidth.

Figure 3.4 shows how a node does bandwidth calculation and what information it should send for bandwidth calculation. This example tells how node B calculates the available bandwidth of the path **BCD**. First, each node broadcasts slot_free message to tell neighbors its free slots, then node C will receive slot_free message from node D, and knows that node D has free slots {1,2,5,6}. Node C now can get the three common free slots {1,2,5} between itself and node D by comparing its own free slots with the message it just received. The node C and node D are one hop away, and so the available bandwidth of path **CD** equals the number of their common free slots, which is three, say BW(CD)=3. The second step, node C modifies the information it got from node D and sends "bw(D,1,2,5)" message, which tells neighbors that if you want me to transfer packets to node D, I may use slots 1, 2 or 5. As node B receives this message, it compares {1,2,5} and the common free slots of itself and node C, say slots {1,2,3} which node B calculated when it receives the slot_free message of node C. Node C cannot receive packets from node B and transfer it to node D concurrently in the same time slot 1 or 2. If node C receives packets from node B in time slot 2, then it can transfer it to node D in time slot 1 or 5. If node C receives packets from node B in time slot 3, then it can transfer it to node D in time slot 1, 2 or 5. To calculate maximum available bandwidth of path **BCD**, node B has to choose one slot from {1,2} the common free slots of node B, node C and node D. It also chooses all the slots in difference set of the common free slots of node B, node C and the common free slots of node C, and get intermediate bandwidth BW*(BC)=2 to destination D. To get BW(BC**),** node B takes the minimum of BW*(BC) and BW(CD) that equals 2. You can image that node B sends packets to node C in slots {2,3}, and node C transfers them to node D in slots {1,5} without interference. Later, node B sends the "bw(D,2,3)" message to node A, then node A will get the available bandwidth of path **ABCD**, says BW(AD)=1 by the same formula.

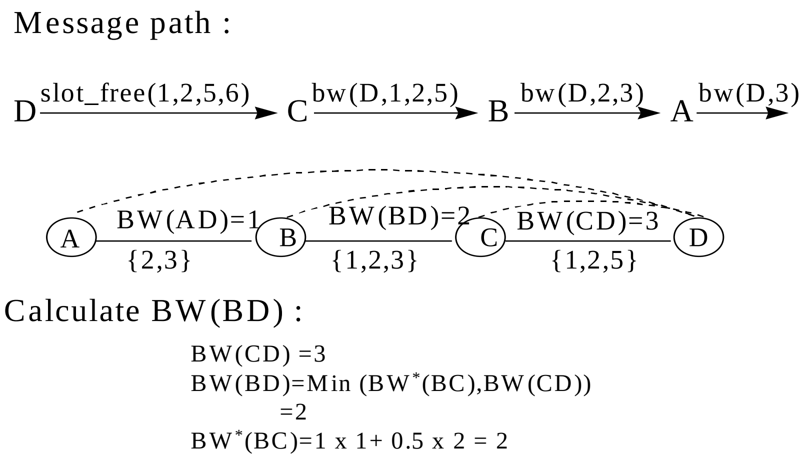

Figure 3.4: A bandwidth calculation example

We generalize the bandwidth calculation formula, shown in figure 3.5. Where C_F_S(xy) indicates the Common Free Slots of node x and y, C_F_S_bw(yz) indicates the slot set of the message type “bw( )”. If node x and y is one hop away, then the available bandwidth equals the number of their common free slots. If their distance is greater than 1, then the available bandwidth equals the minimum of BW*(xy) and BW(yz). In some case, the intermediate result BW*(xy) maybe larger than BW(yz), and so we have to take the minimum of them. To get BW*(xy), it has to calculate the difference of the sets C_F_S(xy) and C_F_S_bw(yz), and the intersection of them. Because node y cannot receive and transfer packets in the same slots, we have to take half slots of the intersection set. If the number of the slots of the intersection set is odd, then we take the largest integer that is smaller than half.

Formal equation:

1. If distance(xy)=1 $BW(xy) = \#(C\_F\_S(xy))$
2. If distance(xz)>1 $BW(xz) = Min(BW^*(xy), BW(yz))$

❖$BW^*(xy) = 1 \times \#(C\_F\_S(xy) - C\_F\_S\_bw(yz))$
$+ 0.5 \times \#(C\_F\_S(xy) \cap C\_F\_S\_bw(yz))$

❖C_F_S indicates Common_Free_Slot
❖C_F_S_bw indicates C_F_S from bw message

Figure 3.5: Formal equation for bandwidth calculation

3.3 Routing

The routing algorithm we used is based on the loop free routing algorithm DSDV. For bandwidth calculations, we combine bandwidth information and routing path into one message, which has five important fields, destination, source, distance, bandwidth and slot condition. First, a node broadcast its slots' condition message will fill the destination field with its own id number and the distance field with zero as well as bandwidth equal to the number of its free slots. When the neighbors receive this message and finish bandwidth calculation, they will transfer the message by filling their id number into the source field and increase the distance field by one. Then the receivers will know that there is a path from itself to node X and passed by node Y, where node X and Y are recorded in destination field and source field respectively. So they can fetch required routing information from the message and record in routing table. The node will discard the message, if the calculation result is not useable. Otherwise it will transfer the message by replacing the source field with its id number, increasing the value in distance field by one, and updating properly the bandwidth calculation according to equations in fig. 3.5. At last, each node builds a routing table for every destination node as shown in figure 3.6, which is a routing table for destination node A according to the topology in figure 3.7. The first row in the table tells that node X can send packets through node B to node A in time slots {1,7}, with distance=2, and bandwidth=2, etc.

At node X, for destination A

next hop	distance	bandwidth	time slot
B	2	2	1,5
C	3	1	5
D	4	1	5

Figure 3.6: A routing table in node X

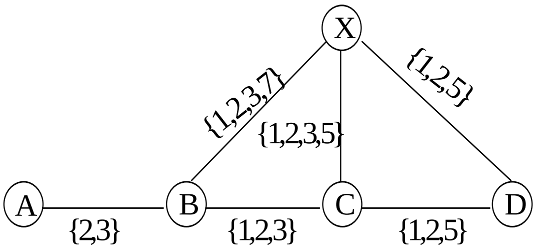

Figure 3.7:Topology for figure 3.6 .

4、 Simulation Study

4.1 Simulation Model

We simulate the bandwidth routing in multi-hop packet radio environment by Maise, a C based, parallel simulation language developed at UCLA[12]. The simulation model structure is shown in figure 4.1,which has two kinds of objects. The first is Coordinator, and the other is mobile stations. In this simulation model, Coordinator is the transmission channel in practice. When node A wants to send packets to node C, it sends the packets to the Coordinator instead. This is because the Coordinator always keeps the updated topology information and the routing table in node A may be out of date. Such that the Coordinator can make the correct judgment of the success or collision of the transmission and process the situations with different channel models. Basically Coordinator will transfer the packets to node C if no collision happens or just discards the packets otherwise.

From figure 4.1, we can see each mobile station has to manage four objects including Connection, Mobility, BW_manager and Statistic to collect information of packet level. The function of Connection is to send packets to destination and report to Coordinator the connection state. The BW_manager is responsible for bandwidth calculation and maintains the routing table for every possible destination. The Statistic keeps the records at packet level such as the probability of packet loss, channel utilization, channel throughput and the channel offered load. The Mobility is to simulate the movement of that mobile station.

We can see that the Coordinator also managers four objects, Synchronizer, Clustering, Call_manager and Statistic to collect connection level information. The main function of the Synchronizer is to synchronize all the mobile stations by informing them of the beginnings of each frame cycle and of each time slot. With this information, each mobile node will know what to do at that time, send packet or keep silent. The Clustering divides all the mobile stations into different clusters. The Call_manager generates calls according to the Poisson arrival equation. The Statistic keeps the record of connection level, such as the probabilities of call blocking (at call set up time), and call dropping (during the service period) which includes dropping due to handover and dropping due to disconnected network.

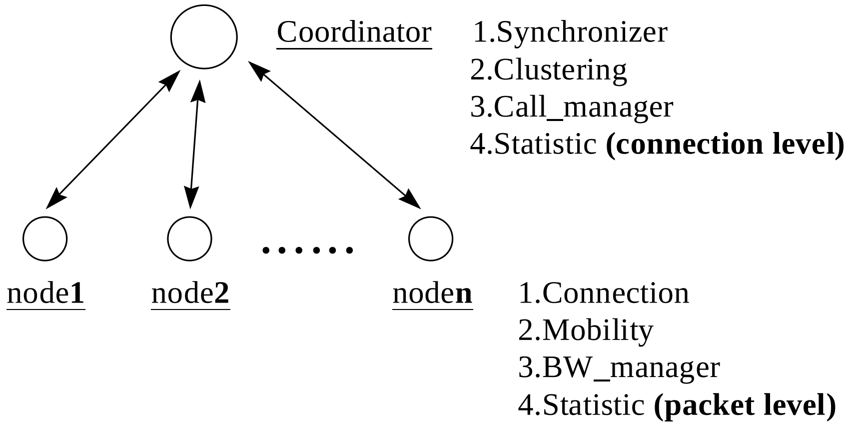

Figure 4.1 Simulation Model

The simulated environment consists of 20 mobile stations randomly roaming in a 10000*40000 feet square. The effective transmission distance of the packets is 10000 feet. We neglect Control Phase of a frame cycle as free, and assume the Transmit phase as 100 ms. There are 10 time slots in the Transmit Phase and each of them is 10 ms. There are eight directions that a station can move. Once the station had decided the direction, it will maintain it within hundreds of frame cycles, then randomly decide the new direction for next period. The mobile station decides to move x feet with probability P at the beginning of every time slot individually. We consider two cases, the first one is when $x = 1$ and $P = 0.5$, the average speed will be 5.5 km per hour for a pedestrian. The second case is when $x = 2$ and $P = 0.5$, and the average speed would be 11 km per hour for a running bicycle. The call arrival and call duration are Poisson equations. The mean call arrival is 11 seconds, and the mean call duration is 90 seconds. The bandwidth required for a call can be 1 or 2 slots depending on voice connection quality.

4.2 Numerical Results

The mobility of stations changes the topology from time to time. Consequently the number of channels also varies due to our clustering algorithm. We show the example topologies which will have three and four channels respectively in figure 4.2 and 4.3. In figure 4.2 node 1, node 2 and node 9 are the cluster heads of channel 1, 2 and 3 respectively. Node 14 and node 18 are the gateways between channel 1 and 3, and node 10 and 16 are the gateways between channel 2 and 3. In figure 4.3, node 1, 2, 3, and 12 are the cluster heads of channel 1, 2, 3 and 4 respectively. Node 7 and 19 are the gateways between channel 1 and 4. Node 5, 9, 10, 14 and 16 are the gateways between channel 3 and 4. Node 8 is the only gateway between channel 2 and 3. Because it is difficult to measure the capacity and end-to end throughput, we define channel offered load as

$$\frac{Num(Offered\_Packet)}{Num(Slot)*Num(avg(Channel))},$$

and collect the packet loss rate, call blocking rate and call dropping rate instead of end-to-end throughput.

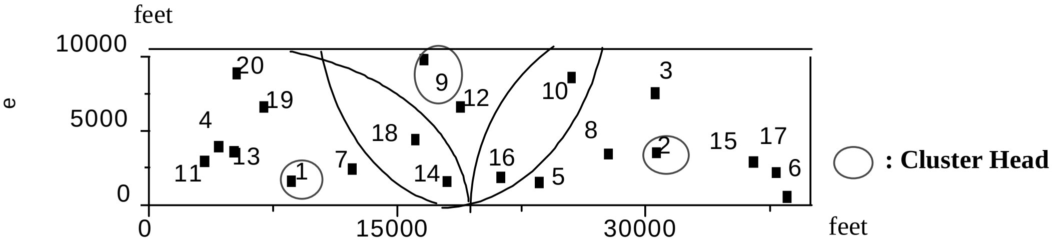

Figure 4.2　Three channels in the topology

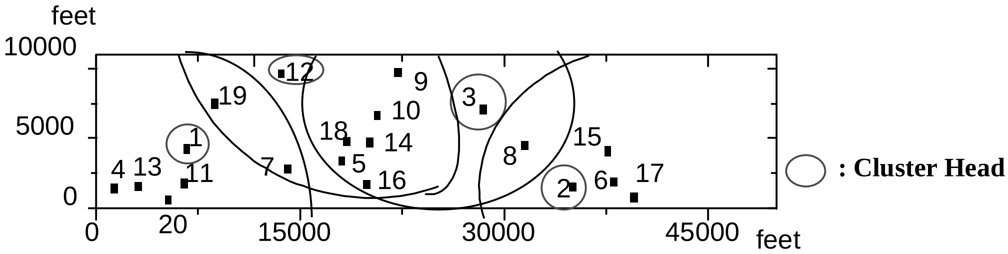

Figure 4.3　Four channels in the topology

We compare three different modes: Qos, Noqos, and Fixed Path. Qos is the base model with bandwidth calculation and available bandwidth information associated with each path in the routing table. If there is enough bandwidth, a connection is accepted and the path with the most bandwidth among the shortest paths is chosen. The Fixed Path model is similar to Qos model, but when the connection has been setup, the path is fixed. If the path becomes disconnected due to topology change, the connection will be dropped without finding an alternative path. In the Noqos model, there is no bandwidth calculation while building the routing table and therefore there is no available bandwidth information with the associated path. Each node decides if the call request should be accepted or blocked according to its routing table which is not aware of the bandwidth of each path.. As long as this node has enough bandwidth to its neighbors, it accepts the request and chooses the shortest path. Like the Qos model, an alternative path will be searched when the original path becomes disconnected.

Loss Rate

We attribute packet loss to two kinds of collisions. The first kind happens in connection setup or re-routing period, because the time slot has not been reserved properly before the routing table is stablized. The second kind is the hidden terminal problem. In figure 4.4, H is the cluster head of cluster 1. H can hear all packets transmitted within cluster 1, and all the nodes in cluster 1 are its neighbors. Node A is not a neighbor of node C and node D because the distance between them are greater than the transmission distance. In time slot 2, for example node C and node D cannot hear the packet sent from node A to node B. Therefore, when node C wants to send a packet to node D, it might use slot 2, which leads to a collision at node B who is a neighbor of both node A and node C. We have eliminated most hidden terminal problems by node copying the slot reservation table of the cluster head, who has done the most completely reservation, to the other nodes in the cluster. But the gateway still keeps its own slot reservation table.

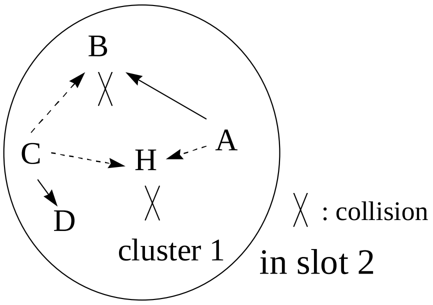

Figure 4.4 Hidden terminal problem

We now examine the relationship between loss rate and offered load and the relationship between loss rate and the moving speed of mobile station. In figure 4.5, the moving speed is fixed in 11km/hr. In figure 4.6 the mean call inter-arrival time is 11 seconds. The Qos model and Fixed path model have recorded which slot can be used in the routing path, such that the packet collision probability is low and the loss rate can be controlled. In Noqos model, when a node wants to setup a routing path, it only considers its own slot reservation table. Especially when the load increases, the Noqos model results in serious congestion. All three models are quite immune to the speed increase, which is because the update frequency of routing table is high enough to timely reflect the current topology.

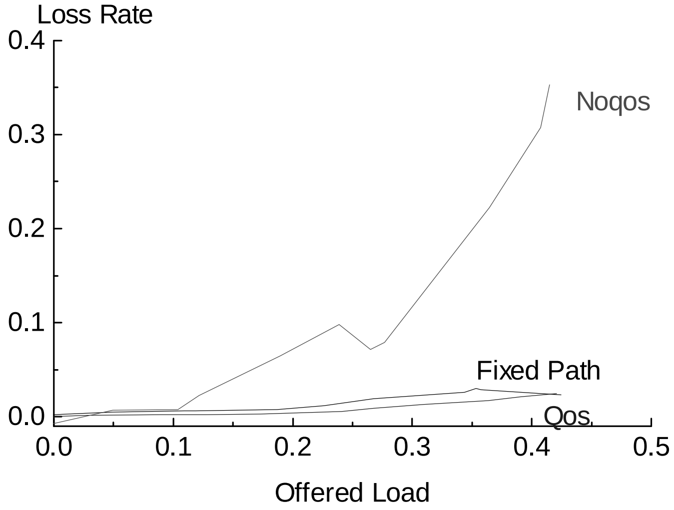

Figure 4.5 Offered Load v.s Loss Rate

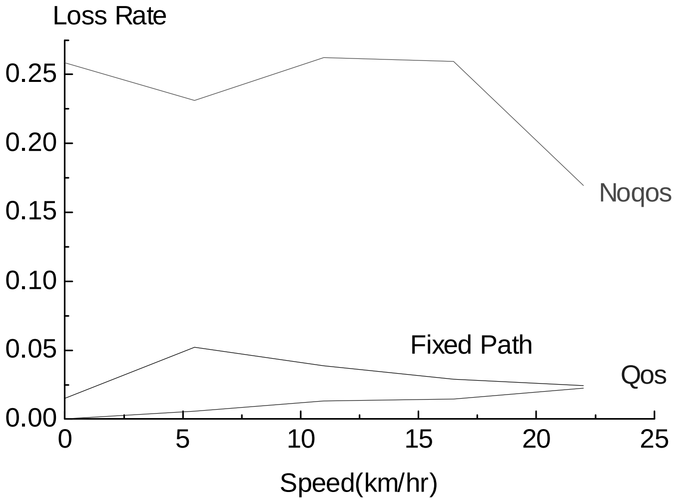

Figure 4.6 Speed v.s Loss Rate

Call Blocking Rate

Figure 4.7 shows the relationship between offered load and call blocking rate, and figure 4.8 shows the relationship between the moving speed of mobile station and call blocking rate. In figure 4.7 the moving speed is kept in 11km/hr and in figure 4.8 the mean call inter-arrival time is 11 seconds. We can see from figures 4.7 that the call blocking rate increases as offered load increases in Qos model and Fixed Path model. In contrast a node in the Noqos model only checks it’s own bandwidth reservation table, as long as the node has enough free slots to its neighbors it accepts the call request and picks the shortest path. We can easily understand why the Noqos mode has much lower call blocking rate than the Qos and Fixed Path models. The offered load has much greater influence than the moving speed as shown in figure 4.8.

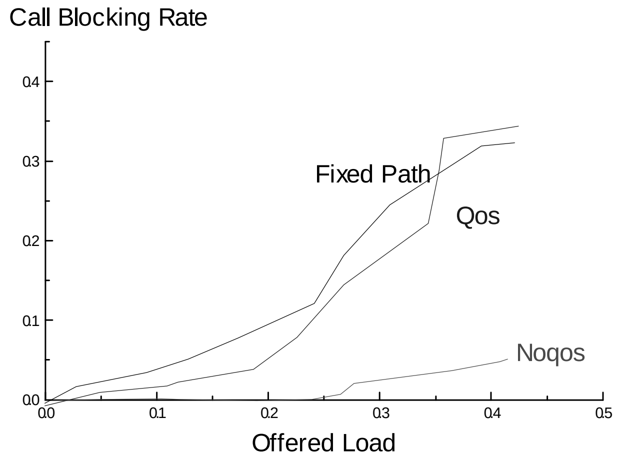

Figure 4.7 Offered Load v.s. Call Blocking Rate

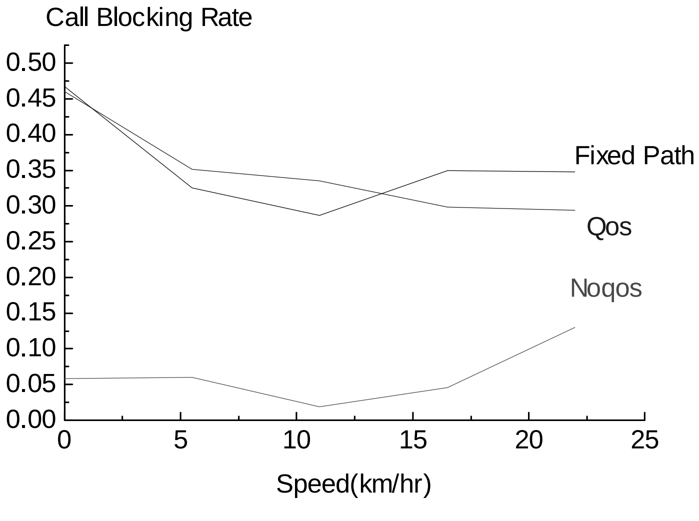

Figure 4.8 Speed v.s. Call Blocking Rate

Call Dropping Rate

Figure 4.9 shows the relationship between offered load and call dropping rate, and figure 4.10 shows the relationship between the moving speed and call dropping rate. The increase of moving speed causes frequent topology change, such that a connection often needs to find a new routing path, but when offered load is high the connection source may not find the new path with enough bandwidth and thus drop the call. We can find that Fixed Path model cannot adjust to mobility because it never tries to find a new path and will drop the call directly. The Noqos model has very low dropping rate because the node only considers its own local reservation. But the path bandwidth may not be available, which results in very serious packet loss.

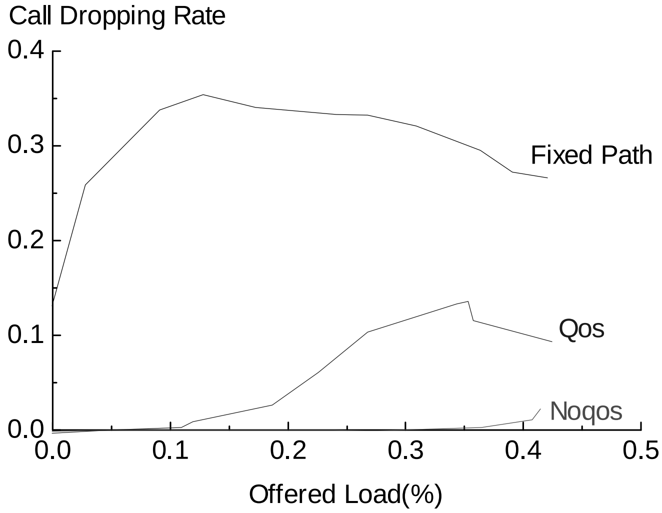

Figure 4.9 Offered Load v.s. Call Dropping Rate

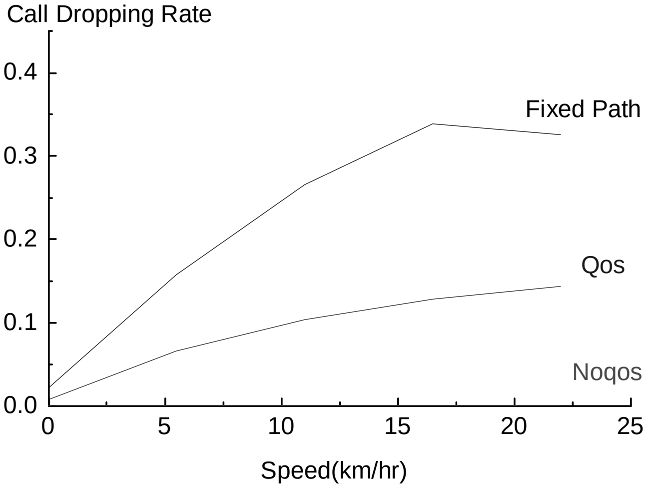

Figure 4.10 Speed v.s. Call Dropping Rate

5 、 Conclusions and Future Work

In this paper, we have presented the bandwidth routing concept and a bandwidth routing algorithm in the multi-hop packet radio environment. First, each mobile station broadcasts its bandwidth reservation table in a special packet, which will travel to any possible destined station. The station along the path compares its own bandwidth reservation table and the reservation information in the packet, calculates the available bandwidth of the path, modifies the reservation information in the packet, then transmits the packet. If the source of the packet is this node's neighbor, then the available bandwidth is their common free slots. If they are not neighbors, the bandwidth is the difference of the common free slot of the node and the neighbor who sends him this packet and the information of the reservation bandwidth in this packet plus half the intersection set of this two sets. Finally, each mobile station will build a routing table for every possible destination, which includes the available bandwidth of each path. With this bandwidth information, the packet loss rate can be very low and the call dropping rate is controlled. This is very important for the connection quality to be guaranteed and thus makes the QoS routing possible for real time traffic in local multi-hop packet radio environment. It also makes this environment compatible with the wired network, such as ATM.

There is still some work to be done with this algorithm in the future. For example, in the simulation model, we can try other mobility model (e.g. Trajectory movement), and call model (e.g. non-Poisson). Also, how and when we should switch to the stand-by path is another important issues. Furthermore, how to utilize this knowledge of bandwidth to accept and control call admission, and dynamically adjust the input flow, etc, in order to improve system capacity. Relationship between mobility and bandwidth can be studied.

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