A Novel Bus Lane Scheme for QoS Routing in Mobile Ad Hoc Networks

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Abstract – Ad hoc networks are multihop wireless networks without fixed infrastructure, whose topology changes frequently and unpredictably. How to issue routes in such networks with sufficient and constant bandwidth is a key problem for some real-time services like audio and video services. This paper proposes a novel QoS solution using code division multiple access (CDMA) scheme, named *CDMA Bus Lane*, which combines the network layer with lower layers together to set up and reserve an interference-free path dynamically for each real-time flow according to its bandwidth requirements. The bandwidth calculation and the channel spreading code assignment method are introduced particularly in this paper. The code used in the Bus Lane scheme is the *Original Variable Spreading Factor* (OVSF) code. Also an on-demand routing algorithm has been proposed to calculate and reserve the bandwidth hop by hop from source to destination.

Keywords- *Ad hoc networks, QoS routing, CDMA Bus Lane, OVSF, code assignment, real-time traffic*

I. Introduction

Mobile Ad hoc networks have been mention as the next generation wireless communication concept, which is an autonomous system consisting solely of mobile terminals connected with wireless links, and no required wired infrastructure. Nodes self-organize and self-configure without help from any centric controller. They operate as hosts as well as routers to communicate through single-hop and multi-hop paths. One of the major challenges faced by the protocol designers is to support *Quality-of-Service* (QoS) in such a multihop mobile network. Especially for real time services, how to issue routes with enough and constant bandwidth is a big problem. Although a lot of work has been done to support QoS in the Internet [1], this work can not be applied directly in the dynamic wireless ad hoc communications. New research is necessary for QoS support in mobile ad hoc networks.

The primary goal of QoS routing protocols is to detect and maintain a path from source to destination with the respect to the desired QoS requirements. Sufficient and constant bandwidth is always the first element to be considered. Most routing protocols for mobile ad hoc networks, such as AODV, DSR, and TORA [2] are designed for best effort routing without considering QoS requirements. Some proposed QoS routing protocols, such as CEDAR [3] and ticket-based probing algorithm [4], are not implemented above a specific MAC layer. In fact, the ability in providing QoS is heavily dependent on how well the resources are managed at the MAC layer. As a MAC layer protocol, IEEE802.11 has been regarded as not suitable for ad hoc networks [5], and some TDMA schemes [6], [7], [8] only make slot reservations within the neighbourhood of the nodes, where the scheduling along a whole path is not considered. Therefore, an approach to implement QoS in ad hoc networks is to consider the network layer along with the lower layers. QoS routing protocols proposed in [9], [10] combine the network and the TDMA MAC layers together to better support QoS. However, compared with TDMA, CDMA is a widely implemented technology for today's wireless networks (3G cellular, IEEE 802.11 and Bluetooth) and allows all terminals to use the entire channel bandwidth at the same time through different spreading codes. Some researchers focus on using CDAM as MAC layer ([11], [12]) to enlarge the capacity of the networks, but again, they do not consider the routing issues.

So far, no work has been done on QoS routing based on CDMA MAC and PHY layers. CDMA Bus Lane proposed in this paper is just such a novel solution to combine different layers to offer better QoS in mobile ad hoc networks.

The CDMA Bus Lane was inspired in the concept of "BUS LANE" used in road traffic control, which keeps interference-free routes for buses from the contention with other vehicles. In network communications, real time traffic needs an end-to-end sufficient and constant bandwidth just like the "BUS LANE" on the streets. So, different services are given to real time traffic (schedule based) and data traffic (contention based).

This paper firstly makes an analysis of the bandwidth problem in a CDMA network, and develops an algorithm for the code assignment and bandwidth calculation on given routes. The QoS Bus Lane routing is generally described according to the code allocation algorithm. The simulations implement the Bus Lane for a number of given routes in an ad hoc network. The blocking rate of requested sessions has been compared among Bus Lane systems with different code sets and even between a CDMA Bus Lane and a TDMA scheme.

II. ASSUMPTIONS AND NETWORK MODEL

Consider a multihop ad hoc network through a common wide-band spectrum spreading channel using CDMA. Traffic is classified into two basic categories: data traffic and real time traffic. All data traffic share the same spreading code channel. Bus Lanes are only built and reserved for real time traffic. The combined layer model is shown in Fig.1. Only symmetric channels are considered, it means, if node *A* can hear from node *B*, node *B* can also hear from node *A*. A separated channel is used to transmit control messages like *HELLO* messages, which helps the nodes to keep local information. Nodes can transmit and receive packets in different spreading codes simultaneously using a pair of separated transmitter and receiver. In order to reduce complexity, mobile terminals are not allowed to perform multiple receptions or multiple transmissions. It means a node can only receive/transmit one packet from/to another node at a time.

A. Topologies of Sessions in Ah Hoc Networks

Basically, there are four types of topologies in ad hoc networks within the concept of CDMA Bus Lanes: (a) parallel road, (b) fly-over crossing road, (c) cross road, and (d) common road (Fig.2).

Because different codes are assigned to the sessions, there is no interference between them in parallel roads and fly-over crossing roads. The bandwidth calculation is just within each session. No outside issue needs to be considered. However, in a cross road topology, two or more sessions cross the same node. No matter what code each session uses, the bandwidth at the cross node is divided by the two or more sessions in the time domain. This happens because only one packet can be received at a time. That is called the *cross road problem*. The common road scenario is similar to the cross road one. So, before the code allocation scheme is proposed, firstly, we assume an ideal scheme that allows cross nodes to schedule the traffic in the time domain to avoid collisions.

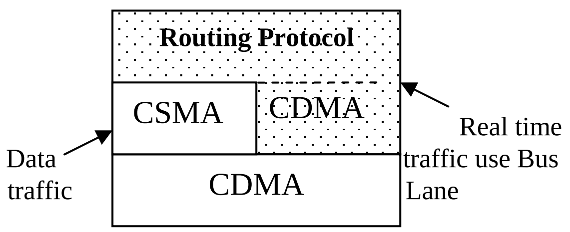

Fig.1. CDMA Bus Lane Model

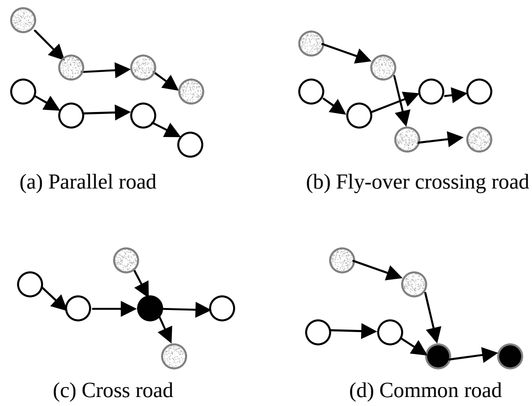

Fig. 2. Four types of topologies between sessions

III. SPREADING CODE AND BANDWIDTH ISSUE

In the implemented CDMA Bus Lane, the spreading codes are the resources to be allocated to each transmission/reception pair along Bus Lane paths. The 3GPP specifications restrict the attention to the case of codes with block length:

$$N = 2^m = SF \tag{1}$$

N represents the number of chips per data symbol, and also the *spreading factor (SF)*. It is important to note that a low spreading factor allows communication at higher data rate but at a cost of having less available spreading codes. However, a higher spreading factor means a lower data rate, but more available spreading codes. Assuming the chip rate *Rc = BWc* (channel transmission bandwidth) is constant, the available data rate Rd is dependent on *SF*.

$$Rd = BWc / SF \tag{2}$$

But in a real time communication, the data rate of a session (*Rs*) is constant, given a *SF*, the required transmission bandwidth (BWt) for the stream is:

$$BWt = SF * Rs \tag{3}$$

And for a reasonable *SF*, the value of *BWt* should be less or equal than the highest available channel bandwidth *BWc* (*BWt <= BWc*). So there will be idle bandwidth (*BWi*) left on this node.

$$BWi = BWc - BWt \tag{4}$$

The *BWi* is useful to allow another Bus Lane session (*cross road problem*) or data traffic across this node.

In the CDMA Bus Lane scheme, a set of orthogonal variable length codes (OVSF codes) are used to give optimal use of the radio channel. Shorter codes allow more streams across the node. On the other hand, longer codes enlarge the set of available spreading codes. In the scheme, all variable length codes work together in order to allocate QoS Bus Lane routes for each real time session as well as increasing the throughput of the whole ad hoc network.

A. Orthogonal Variable Spreading Factor (OVSF) Codes

The recursive generation of the OVSF codes tree [13] is described in Fig.3.

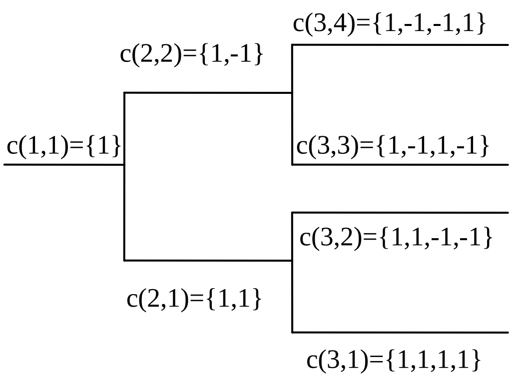

Fig.3. The structure of OVSF tree.

c (i, j) means the jth code at level i. It can generate two children codes *c (i+1, 2j)* and *c (i+1, 2j -1)* by the rule:

$$\begin{cases} c(i+1, 2j) = \{c(i, j), -c(i, j)\} & (5) \\ c(i+1, 2j-1) = \{c(i, j), c(i, j)\} & (6) \end{cases}$$

The *SF* at level *i* is 2^{i-1}, and the number of available codes at this level is also 2^{i-1}. All the codes in each level are mutually orthogonal. This is also true for codes of different levels, except when one code is an ancestor of the other. Once a particular code is used in a node, neither its descendants nor its ancestors can be assigned within the node's transmission range.

IV. Code Allocation and Path Bandwidth Calculation

A CDMA Bus Lane is built by a set of spreading codes *C = {c1, c2, c3 … cm}* generated by the OVSF tree. In order to simplify the problem, let's assume all codes in set *C* are orthogonal with each other, and they are ordered from a minimum *SF* to a maximum *SF*. Using this set, a node is not affected by any transmission originated outside its neighbourhood. So, codes can be reused outside of the node's transmission range. In order to initiate a transmission from *ni* to its neighbour *nj*, represented by the *link (i, j)*, the selection of a transmission code *ck* must consider the scheduled codes from both of those two nodes and their neighbours. Let *RCi* represent the set of codes which node *ni* is required to receive from its neighbours *NBi* (the set of neighbouring nodes of *ni*), and *TCi* is the transmission code set used by node *ni*. Obviously, as a transmission code for the *link (i, j)*, *ck* can be neither in set *RCi* nor in set *TCj*, but the codes in *TCi* or *RCj* can be reused because different codes can not contribute to more transmissions on the same node at the same time(see section II). Let *RCx* be the receiving code set of the nodes in *NBi*, and *TCy* be the transmission code set of the nodes in *NBj*. The transmission from node *ni* can affect the reception of its neighbouring nodes in *NBi*. However, the interference code set caused by *NBi* is *ICx*= (*RCx* – *TCi* – *RCj*), because some codes in *RCx* belong to the links from *ni* or to *nj* whose codes have been recorded in the sets *TCi* and *RCj*. Similarly, *ICy* = (*TCy* – *TCi* – *RCj*) represents the interference code set caused by *NBj*. Therefore, the set of codes $AC_{i \to j}$, which can be used for transmission from *ni* to *nj* without interference is described by:

$$AC_{i\to j} = \overline{RC_i \cup TC_j \cup IC_x \cup IC_y}$$
$$(IC_x = (RC_x - TC_i - RC_j),\ IC_y = (TC_y - TC_i - RC_j)) \qquad (7)$$

In an ad hoc network represented by a graph G with a set of nodes *N* and a set of links *L*, *G = (N, L)*, each node can get the information from its neighbours by *HELLO* messages, which are local one-hop broadcasts. For any node *ni* on a given path $P = \{n_0 \to n_1 \to \ldots \to n_i \to \ldots \to n_{m-1} \to n_m\}$, the available code set $AC_{i\to i+1}$ $(i=0,1,\ldots,m-1)$ can be calculated by (7). A transmission code TC_i^p, where *p* means the path *P* and *i* means node n_i, should be assigned to each node along the path *P* except the node n_m, which is the destination node. But when the code TC_i^p is pre-assigned, it also affects the nodes within the next two hops on Path *P*. So the available transmission code set on node n_i for path *P*, represented by AC_i^p, should be:

$$AC_i^p = AC_{i\to i+1} - TC_{i-1}^p - TC_{i-2}^p \qquad (\textit{if}\ x<0,\ TC_x^p = \varnothing) \qquad (8)$$

Also, the selected codes must satisfy the bandwidth requirement of the session. It is necessary that every node along the path finds a code with the *SF* that satisfies the condition:

$$R_s * SF <= BW_i \qquad (9)$$

BW_i is the available channel bandwidth (see (4)). If there is no other session across the node, BW_i is equal to BW_c, and the available channel bandwidth is the maximum channel bandwidth. Equation (9) should be considered on both transmitter and receiver of a node, because they are separated.

Obviously, smaller *SF* allows more traffic on the node. So n_i always prefers codes with shorter length (code c_i with minimum index number) in the code set AC_i^p . The code allocation algorithm on a certain path *P* is as follows:

i) From *i=0 to i=m-1*

If there has been a code $TC_i^{p'}$ assigned to the link ($n_i \rightarrow n_{i+1}$), due to another path crossing this link (common road scenario), then:

$$TC_i^p = TC_i^{p'} \tag{10}$$

Because the two transmissions on the same link can not be done at the same time even if different codes are given. Using the same code can save code resources.

ii) *Else*

Find the used $\overline{AC_{i->i+1}}$ (it is easier than finding $AC_{i\rightarrow i+1}$) by (7) and the reserved codes for the nodes within two hops on the path by the function: *find_unavailable_codes* (n_i, n_{i+1}).Then the *unavailable code set* (*Cun*) can be represented by:

$$Cun = \overline{AC_{i->i+1}} \cup TC_{i-2}^p \cup TC_{i-1}^p \quad (if\ x<0,\ TC_x^p = \emptyset) \tag{11}$$

Find the first code in set *C* which is not equal to any code in the set *Cun* .

$$TC_i^p = select\_code(\overline{AC_{i->i+1}} \cup TC_{i-2}^p \cup TC_{i-1}^p) \tag{12}$$

iii) For the receiving code of node n_{i+1}:

$$RC_{i+1}^p = TC_i^p \tag{13}$$

iv) After allocating a code to the link ($n_i \rightarrow n_{i+1}$), increase the index i by i++. And the available bandwidth after code assignment is described by:

$$BW_i = BW_i - R_s * SF \tag{14}$$

The bandwidth on both transmitter and receiver of a node is estimated using (14). If the calculated BW_i is less then zero, the route request fails.

This algorithm is in fact a greedy scheme which seeks local maximum available bandwidth hop by hop on a real time path. With this algorithm, the code channels can be allocated dynamically on the existing routes and it also keeps the bandwidth interference free from end to end.

V. BUS LANE ROUTING PROTOCOL

The algorithm mentioned in section IV is not a real QoS routing protocol, because the code allocation and the available bandwidth calculation are just performed on given routes. These routes are not selected with respect to bandwidth, which makes the bandwidth reservation on some routes fail. A good routing protocol requires finding a route with sufficient bandwidth from source to destination. The bandwidth calculation and code allocation should be done in the routing discovery stage. That is what the Bus Lane scheme is required to realize.

As an on demand routing protocol, AODV is selected to help to set up such a QoS Bus Lane. AODV uses *HELLO* messages to manage local information. In this way, the bandwidth and code information of the neighbours can be easily exchanged. AODV initiates a path discovery by broadcasting a RREQ route request to its neighbours. The Bus Lane scheme can use the RREQ in order to bring the bandwidth requirement. If the neighbour can not find a code that satisfies the bandwidth requirement, it denies the request. If a RREQ can get to the destination, that means a route with sufficient bandwidth is found and a Bus Lane is set up and reserved by a reply message, called RREP, from the destination back to source along the found path. In order to guarantee the bandwidth on the whole route, only the destination node has the right to answer the RREQ.

In the Bus Lane discovery stage, it appends the following information to the RREQ message: {Session ID, $BWd, TC_{i-2}^p, TC_{i-1}^p$ }.

(TC_{i-2}^p, TC_{i-1}^p) are the codes selected by the last two hops. So the bandwidth can be calculated with the transmission of the RREQ. If there are more than one found route, the destination node will reply to the first route that reaches it, which is regarded as the shortest route with enough bandwidth.

VI. SIMULATIONS OF CODE ALLOCATION

Because this research is an on going work, only simulations about codes allocation on given routes has been performed.

The simulations are implemented by using OPNET simulator. A hundred nodes are generated in an area of 2000*2000 m^2 . The location of a node is generated randomly using a uniform distribution. The transmission range for each node is 300m. The simulator randomly selects a pair of source and destination nodes for each session. The route between the two nodes is given by an optimal shortest routing algorithm. Assume the required data bandwidth in each session is *BWd* = 32kbps, the *SF* changes in the range [8, 128], which are between *level 3* and *7* of an OVSF code tree. We use the *n-codes-remain* scheme to build the code set, which means each layer leaves *n* codes as roots to generate codes for the next level. The maximum channel bandwidth is: *BWc = BWd * SFmax.*

The performance in block rate of different *n-codes-remain* code sets have been simulated with *n*=1, 2, 4, 8, and the results are shown in Fig.4. It is obviously that, *n*=1 give less available codes but with the shortest *SF*, which gives more opportunity to cross roads, and n=8 give more available codes with longer *SF.* The blocking rate was calculated by: the number of sessions over the number of denied sessions. The result shows that, to select the value of *n*, the network load should be considered.

Another simulation was performed comparing the CDMA Bus Lane scheme with another scheme using TDMA. *4-codes-remain* code set is implemented in the CDMA Bus Lane (shown in Fig. 5).

The TDMA scheme uses a time slot allocation algorithm which is similar with the one proposed in [6], where time slots are assigned for a given route to set up an uninterrupted path. All the sessions just share the same code channel, where minimum *SF= 8* is used to generate the spreading code. That means, *SFmax/ SFmin = 16* sessions at most can be scheduled in the same transmission range at one time. And if a transmission can not find enough time slots, the request is denied.

The simulation results show the CDMA Bus Lane scheme provides better performance than the TDMA scheme when the number of required QoS call sessions increase.

VII. CONCLUTION AND FUTURE WORK

A novel QoS solution named CDMA Bus Lane has been proposed. The code allocation algorithm has been introduced and implemented in a simulation model. The QoS Bus Lane routing is generally described according to the code allocation algorithm.

The CDMA Bus Lane scheme is a new concept, which looks on the network layer and the lower layers as a whole to make the QoS mechanisms more effective and easier to implement in a real ad hoc network. The work is still in an early stage, but the simulation results show a good expected performance of the proposed scheme.

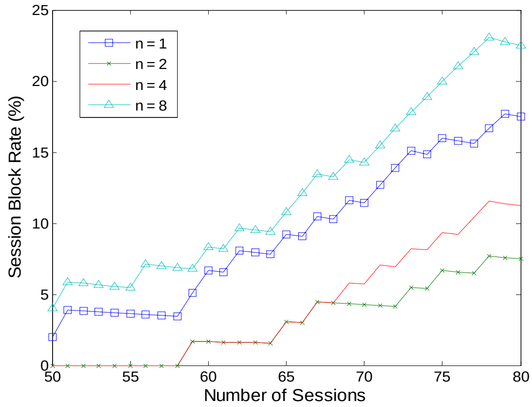

Fig.4.Performances of different *n-codes-remain* code set in block rate.

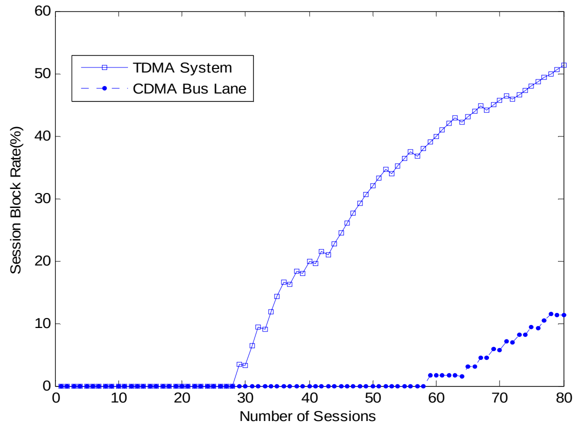

Fig. 5. Block rate against the number of QoS sessions from 0 to 80 of tow different systems (CDMA Bus Lane vs TDMA).

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