CDMA Bus Lane: a novel QoS solution for real-time traffic in ad hoc networks

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Abstract:
Ad hoc networks have obtained a growing interest because of their advantages in many practical applications. One of the major challenges faced by the 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 key problem. This paper proposes a novel QoS solution, named CDMA Bus Lane, which dynamically sets up and reserves an interference-free path for each real-time flow according to its bandwidth requirements. The bandwidth calculation and the channel code assignment method are introduced here. Also a routing algorithm has been proposed to calculate and reserve the bandwidth hop by hop from source to destination combining an on-demand routing layer together with CDMA MAC and PHY layers.

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

1. INTRODUCTION

The mobile Ad hoc network has been mentioned 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 can self-organize and self-configure without help from any centric controller. All the nodes in Ad hoc networks operate as hosts as well as routers to communicate through single-hop and multi-hop paths. It makes the protocol design for such a network interesting, but difficult. With the expanding requirements in the applications of mobile Ad hoc networks, especially in the area of audio and video services, quality of service (QoS) support is necessary. It is true that a lot of work has been done in supporting QoS in the Internet [1]; however, this work cannot be applied directly in the ad hoc communications, because of its wireless medium, bandwidth constraints and dynamic network topology.

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 in terms of bandwidth, loss, jitter, delay and traffic conditions. 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 without considering QoS requirements. Some proposed QoS routing protocols, such as CEDAR [3] and ticket-based probing algorithm [4], are not implemented on 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. IEEE802.11 has been regarded as not suitable for ad hoc networks [5], and some TDMA schemes [6], [7], [8] are only designed to make reservations within the neighbourhood of the nodes, where the scheduling along a whole path is not considered. [9], [10] have proposed QoS routing protocols for ad hoc networks using TDMA as multiple access technique, and they combine the network and the MAC layers together to better support QoS. So an approach to implement QoS in ad hoc networks is to consider the network layer along with the lower layers. Compared with TDMA, CDMA allows all terminals to use the entire channel bandwidth at the same time through different spreading codes. Some researches focus on using CDMA as MAC layer [11], [12], 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. A novel QoS solution named CDMA Bus Lane proposed in this paper, however, is just such a scheme.

The CDMA Bus Lane was inspired in the concept of "BUS LANES" 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 the aim of the CDMA Bus Lane is to establish QoS routes with guaranteed bandwidth for all types of real time traffic in mobile ad hoc networks. For data traffic, a special contention channel is assigned. That means different services are given to real time traffic (schedule based) and data traffic (contention based). The CDMA Bus Lane also carefully considers the condition of currently used wireless networks (3G cellular, IEEE 802.11 and Bluetooth), almost all of them implement CDMA as multiple access technique, which makes the CDMA Bus Lane more adaptive. In addition, the Bus Lane takes the advantage of variable length codes, which allows optimal use of the radio spectrum. That means different spreading codes can use different spreading factors. Finally, the route discovery in the CDMA Bus Lane should base on an on-demand routing protocol, and sets up the path only when needed. Each real time session calculates the bandwidth hop by hop with the route request message and selects the links with sufficient bandwidth. When the discovery finishes successfully, a route with sufficient bandwidth is found and reserved at once.

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 some given routes. The algorithm is then combined with an on-demand routing protocol. The simulations show the code allocation and the blocking rate of requested sessions of two ad hoc networks, one using CDMA Bus Lane scheme and the other using a TDMA scheme.
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. Perfect synchronization and power control are also assumed for such a CDMA system.

2.1 Topologies of Sessions in Ah Hoc Networks

Basically, there are four types of topologies in ad hoc networks within the concept of CDMA Bus Lane: (a) parallel road, (b) fly-over crossing road, (c) cross road, and (d) common road. (Fig. 1)

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.

Fig. 1. Four types of topologies between sessions

3. Spreading Code and Bandwidth Issues

In the implemented CDMA Bus Lane, the spreading codes are the resources to be allocated to each node along Bus Lane paths. Spreading codes are sequences of pseudo random bits that are used to expand the bandwidth occupation in a CDMA system. Data symbols are multiplied by orthogonal spreading sequences. The 3GPP specifications restrict the attention to the case of codes with block length:
$N = 2 \text{ m} = SF$

$N$ 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 communication at a lower data rate, but more available spreading codes. Assuming the chip rate $R_c = BW_c$ (channel transmission bandwidth) is constant, the data rate $R_d$ is dependent on $SF$.

$R_d = \frac{R_c}{SF}$

But in a real-time communication, the data rate of a session $(R_s)$ is constant, given a $SF$, the required transmission bandwidth $(BW_t)$ for the stream is:

$BW_t = SF \times R_s$

And for a reasonable $SF$, the value of $BW_t$ should be less or equal than the highest available channel bandwidth $BW_c$ ($BW_t \leq BW_c$). So there will be idle bandwidth $BW_i$ left on this node.

$BW_i = BW_c - BW_t$

$BW_i$ is useful to allow another Bus Lane session (cross road problem) or some data traffic across this node. For example, in Fig. 2, the data rate is 1 unit, the $SF$ is 4, and transmission bandwidth of the data is $1 \times 4 = 4$ unit/s. However, because the channel transmission bandwidth is 8 unit/s, there are 4 unit chips left idle per second. This left bandwidth gives an opportunity for other traffic across the node, whose $BW_t$ is less or equal than 4 unit chips per second.

Fig. 2. The relationship among $R_s$, $BW_t$, $BW_c$, and $BW_i$, where $BW_i$ can be used by another session or data traffic across the 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. As the data rate $R_d$ is constant in a QoS session, shorter codes are used in order to allow more streams across the node. It is a different approach from the one used in [13], that uses shorter codes in a node in order to increase the data rate for a single stream. On the other hand, longer codes enlarge the set of available spreading codes (an example is shown in the OVSF tree in Fig. 3). In the scheme, longer codes enlarge the set of available spreading codes (an example is shown in the OVSF tree in Fig. 3).
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.

3.1. Orthogonal Variable Spreading Factor (OVSF) Codes

The recursive generation of the OVSF codes tree [14] is described in Fig. 3.
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:
c(i+1, 2j) = {c(i, j), -c(i, j)}
(5)
c(i+1, 2j-1) = {c(i, j), c(i, j)}
(6)
c(3, 4) = {1,-1,-1,1}
C(2, 2) = {1,-1}
c(3, 3) = {1,-1,1,-1}
C(1, 1) = {1}
c(3, 2) = {1,1,-1,-1}
C(2, 1) = {1,1} c(3, 1) = {1,1,1,1}
Fig. 3. The structure of OVSF tree.
The SF at level i is 2^{i}, 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,
ext除非 one code is an ancestor of the other. Once a particular code is used in a node,
nor its descendants nor its ancestors can be assigned within the node's transmission range.

4. CODE ALLOCATION AND PATH BANDWIDTH CALCULATION

A CDMA Bus Lane is built by a set of spreading codes \( C = \{c_1, c_2, c_3, \ldots, c_m\} \) 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 originate outside its neighbourhood.
So, codes can be reused outside of the node's interference range. In order to initiate a
transmission from \( n_i \) to \( n_j \), represented by link (i, j), the selection of a transmission code
must consider the scheduled codes from both of the two nodes and their neighbours. Let
\( R_{C_i} \) represents the set of codes which node \( n_i \) is required to receive from its neighbours
(\( N_{B_i} \) (the set of neighbouring nodes of \( n_i \)), and \( T_{C_i} \) is the transmission code set used by node
\( n_i \).

Obviously, as a transmission code for the link (i, j), \( c_k \) can be neither in set \( R_{C_i} \) nor in set
\( T_{C_j} \), but the codes in \( T_{C_i} \) or \( R_{C_j} \) can be reused because each node has only a single pair of
transmitter and receiver. More codes cannot contribute to more transmissions on the same
node at the same time, once the channel is scheduled by time. At the same time, the
interference from the \( N_{B_i} \) and \( N_{B_j} \) need to be considered as well. From \( n_i \)'s view, the
transmission from \( n_i \) to \( n_j \) should avoid interference with the reception codes of the nodes in
\( N_{B_j} \) and \( N_{B_j} \).
Let's collect all the reception codes from NBi into a set called $\text{RC}_x$, where the elements of this set are identified by their reception code value and source-destination pair. Obviously, not all of them affect the code allocation for link $(i, j)$. We can ignore those reception codes starting at the node $n_i$, which belong to $\text{TC}_i$, and all the reception codes of node $n_j$, which has been represented by $\text{RC}_j$. So the interference code set from the NBi can be represented by $\text{NC}_i$:

$$\text{NC}_i = \text{RC}_x - \text{TC}_i - \text{RC}_j$$

(7)

By the same way, the interference code set from the NBj can also be presented by:

$$\text{NC}_j = \text{TC}_y - \text{TC}_i - \text{RC}_j$$

(8)

Therefore, the set of codes $\text{AC}_i \cap j$, which can be used for transmission from $n_i$ to $n_j$ without interference is described by:

$$\text{AC}_i \cap j = j_i \text{NC}_N \text{CTC} \cup \cup \cup$$

(9)

In order to satisfy a session with a bandwidth of $R_d$ on a given path $P$, it is necessary that every node along the path finds a code with the SF that satisfies the condition:

$$R_d \times \text{SF} \leq \text{BW}_i$$

(10)

$\text{BW}_i$ is the available channel bandwidth. If there is no other session across the node, $\text{BW}_i$ equals to $\text{BW}_c$, and the available channel bandwidth is the maximum channel bandwidth.

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 $n_i$ on a given path $P = \{n_0 \rightarrow n_1 \rightarrow \ldots \rightarrow n_i \rightarrow \ldots \rightarrow n_{m-1} \rightarrow n_m\}$, the available code set $\text{AC}_i \cap i+1 (i=0,1,\ldots,m-1)$ can be calculated by equation (9). A transmission code $\text{TC}_p_i$, 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. Also, the selected codes must satisfy the bandwidth requirement of the session. On each link $(i \rightarrow i+1)$ along the path, the bandwidth calculation is performed on the receiving node for both the transmission on $n_i$ and the reception on $n_{i+1}$. Let $\text{BW}_{i}(t)$ be the idle transmission bandwidth of the node $n_i$, $\text{BW}_{i}(r)$ represents the idle receiving bandwidth of the node $n_{i+1}$.

The available data bandwidth (in this paper, data bandwidth means the bandwidth of the data before spreading) on link $(i \rightarrow i+1)$ can be represented by:

$$\text{BW}_a(i \rightarrow i+1) = \min\{\frac{\text{BW}_i(t)}{\text{SF}(i)_t}, \frac{\text{BW}_{i+1}(r)}{\text{SF}(i)_t}\}$$

(11)

And the available end-to-end data bandwidth ($\text{BW}_a(P)$) for the whole path $P$ is:

$$\text{BW}_a(P) = \min\{\text{BW}_a(i \rightarrow i+1)\} (i=1, 2, \ldots, m-1)$$

(12)

That means the link with minimum available bandwidth on the path $P$ is the bottleneck of the bandwidth along the path. Equation (11) shows that a smaller $\text{SF}$ contributes to a larger $\text{BW}_a$.102
So ni always prefer codes with shorter length (code ci with minimum index number) in the code set ACiÆi+1. Once ni selects its transmission code TCp, it will also affect the code allocation for the transmission of node ni+1, and node ni+2. 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'p,i assigned to the link (niÆni+1) due to another path crossing this link (common road scenario), then:

TCp,i = TC'p,i (13)

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 the code resource.

ii) Else

Find the used 1+i>−iiACi (it is easier than finding ACiÆi+1) by equation (9) and the reserved codes for the nodes within two hops on the path by the function: find_unavailable_codes (ni, ni+1). Then the unavailable code set (Cun) can be represented by:

Cun = 1+i>−iiACp,i ∪ TCp,i ∪ TCp,i TCTC (14)

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

TCp,i = select_code (1+i>−iiACp,i ∪ TCp,i ∪ TCp,i TCTC) (15)

iii) For the receiving code of node ni+1:

RCp,i = TCp,i (16)

iv) After allocating a code to the link (niÆni+1), increase the index i by i++.

The available data bandwidth on link (niÆni+1) can be calculated by equations (11). If the required data bandwidth BWd is larger than BWa(P), the route request fails, or the algorithm will go on until get the destination node nm.

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.

5. BUS LANE ROUTING PROTOCOL

The algorithm mentioned in section 4 is not a real QoS routing protocol, because the code allocation and the available bandwidth calculation are just 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 the source to the 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 by a RREP message to confirm the reservation on each link.

In the Bus Lane discovery stage, it appends the following information to the RREQ message: {Session ID, BWd, pi, TCTC, Time schedule of ni}. (pi, pi TCTC) are the codes selected by the last two hops. We need the time schedule information of node ni in order to solve the cross node problem and the bandwidth calculation. So the bandwidth can be calculated with the transmission of the RREQ hop by hop. If there are more than one found route, the destination node will reply to the first route that reaches it, which is regard as the shortest one with enough bandwidth.

6. SIMULATIONS OF CODE ALLOCATION

Because this research is an ongoing 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 m². The location of a node is generated randomly using a uniform distribution. The transmission range for each node is 300m. The number of sessions required to be set up is NS. 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. The number of total links for the sessions is NL, and the number of required codes is NC. 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. From level 3 to level 6, each layer leaves four codes as roots to generate codes for the next level. The maximum channel bandwidth is: BWc = BWd × SFmax.

Table 1 shows a series of performed simulations. For each simulation, a certain number of sessions were requested. The proposed code allocation algorithm (section 4) was used for each requested session. Table 1 shows the calculated number of links needed for the requested sessions and how many codes were needed to avoid interference between Bus Lanes (the codes on failed session were not account). For each requested session a bandwidth calculation was performed. If there was no enough bandwidth for a session, the request was denied. The number of denied sessions (ND) is also given in the table.
Table 1

<table>
<thead>
<tr>
<th>Number of Sessions</th>
<th>Session Block Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDMA System</td>
<td></td>
</tr>
<tr>
<td>CDMA Bus Lane</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 4 Block rate against the number of QoS sessions from 0 to 80.

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.
7. CONCLUSION 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.

CDMA Bus Lane 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.

REFERENCES

1. XiPeng Xiao and Lionel M. Ni "Internet QoS: A Big Picture", IEEE Network, March/April 1999