Seminar: Distributed and Networked Systems

TDMA-based Multicast-QoS-Routing-Approaches for Mobile Ad Hoc Networks

Johann Gebhardt
(gebhardt.johann@gmail.com)

September 15, 2014

1 Introduction

Mobile ad hoc networks are networks containing several mobile nodes with a dynamic network topology. The nodes communicate over a wireless medium like WLAN with each other. Due to the limited range of mobile communication, it is often necessary to use multi-hop communication. In this case it is necessary to relay the messages from one node to another neighboring node until the destination is reached. The goal of routing protocols is the creation of efficient paths from a source node to one or more destination nodes.
Mobile networks are a topic of increasing importance. A lot of new devices, like mobile phones or tablets, rely completely on mobile communication. Additionally, mobile communication can be important in manufacturing scenarios. Autonomous robots performing simple and increasingly difficult tasks are more and more common. It can be a huge advantage to use mobile, instead of stationary, robots in some cases. Mobile robots can move around in a certain range, which increases their possible functionality compared to immobile robots. Using wired communication for mobile robots is extremely unpractical as it hinders their range of motion and therefore limits their advantages over stationary robots.
Wireless communication is always broadcast, even if there is only one destination. Multiple devices sending at the same time will lead to collisions with other transmissions in a certain area. That means that some messages cannot be received properly. There are several mechanisms to allow nodes to communicate collision free. One mechanism is the Time Division Multiple Access (TDMA) network model, in which time is split into slots and nodes are scheduled to send / receive in a slot without interfering with other nodes. TDMA has the advantage that it allows deterministic guarantees regarding bandwidth and delay. Deterministic guarantees, or Quality of Service (QoS) guarantees, can be important in a lot of applications, especially in situations with real-time requirements. QoS routing protocols do not only find suitable routes, but routes that can fulfill some QoS requirements, e.g., a bandwidth requirement. The TDMA model allows such guarantees as long as there is no interference from other networks or other applications (single network property) [7].
Another common use case is sending messages from one source to several destinations. For example, this can be the case in a streaming service with several mobile clients or a sensor sending its data to several mobile nodes. Finding multiple unicast routes and then sending the message(s) several times is not really efficient, therefore having multicast routes, routes with one source and multiple destinations, is helpful.

2 Basics Concepts and Related Work

The main part of this paper examines four different protocols for multicast-QoS-routing in TDMA-based networks. These protocols share several key concepts which are presented in the following.

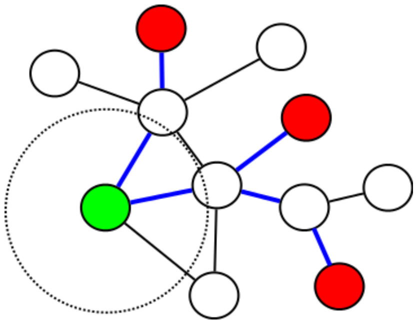

Figure 1: A multicast route with one sender and several destinations

2.1 Multicast Routing

Multicast routing is the process of creating a route from one sender to several destinations at once. When modeling the network as a graph, this results in a tree-like route with the sender as the root and the destinations as the sinks of the tree (Figure 1). Multicast routing can lead to an increased performance compared to multiple unicast routes. Often there will be a shared (part of a) path from the source to the different destinations. If that is the case, multiple unicast routes could send the same data along the same path multiple times, which can be waste a of resources. Another thing to consider is the broadcast nature of the wireless medium. During wireless communication, packets are always broadcasted, even if they are only intended to be received by one node. Using this property to reach several receivers with a single transmission results in an increased performance. Multicast routing has been studied by several group of researchers. For example "The core assisted mesh protocol" [6], "On-Demand Multicast Routing Protocol" [9] , "Spiral-Fat-Tree-Based On-Demand Multicast Protocol (SOM)" [3] or "Multicast Ad hoc On-Demand Distance Vector (MAODV) Routing" [13] are all multicast routing protocols.

2.2 Quality of Service

Quality of Service (QoS) is a measurement of the overall performance of a network. The overall performance is usually described as a set of parameters, so-called **QoS-parameters**, which can be used to evaluate specific performance criteria. A common QoS-parameter is bandwidth. The bandwidth is a representation of the throughput of a link, often measured in bits per second or – in the case of TDMA – in the number of free timeslots. Another important parameter is the end-to-end delay of a transmission, which represents the time needed to send a message from a source to a destination. It can be measured in time or hops in multihop routes. These are the two most important QoS-parameters in the context of this summary. There are other QoS-parameters, e.g., the energy consumption of devices or the error rate (packet loss rate) of the communication, that are of interest in other application contexts.

QoS routing protocols do not only find a route from a source to a destination, instead they find a route that can fulfill some QoS requirement(s). Such algorithms have, for example, been studied by Lin and Liu [10,11] or Chen et.al. [1,2].

2.3 Time Division Multiple Access

TDMA (Time Division Multiple Access) is a medium access method used for distributed networks. It allows several nodes to communicate over a shared medium in a collision-free manner. In this model, the medium access is organized by time, such that only nodes that can transmit without interfering with other nodes send at a certain point in time. Time is splitted into slots of a certain, fixed length and those slots are allocated to the nodes for sending or receiving messages.

For a successfull transmission the sender and the receiver have to be scheduled to send / receive in the same

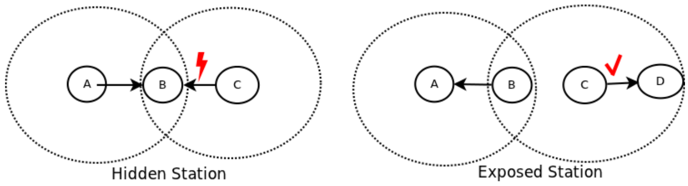

Figure 2: The hidden and exposed station problem

timeslot. Furthermore, the transmissions of one node interfere with transmissions of other nodes in a certain range (interference range). Therefore nodes have to be blocked form sending / receiving in some slots.

2.4 Space Division Multiple Access

A simple way of scheduling communication in the TDMA model would be allowing only a single node in the network to send at any time. This would reduce the scheduling problem to determine which node sends and receives in any timeslots. However, wireless communication always has a maximum range. A device cannot communicate with nodes outside of that range. Unfortunately, the range in which a transmitting node interferes with the communication of other nodes is usually greater than the communication range. The interference range is often assumed to be about two times bigger than the communication range.
The timeslot reuse capability states that two nodes can communicate at the same time as long as their communications do not interfere with each other. This is also known as Space Division Multiple Access (SDMA). When nodes are scheduled to send at the same time, two problems have to be taken into acccount. The first is called hidden station problem. It occurs when two nodes, outside of each other's communication range (nodes A and C in Figure 2), want to send to the same node (B) at the same time. This will lead to a collision at the receiving node. The problem can be resolved with a RTS-CTS mechanism, in which the second node (e.g., node C) receives the CTS message from the intended destination and therefore knows that it cannot send at the moment. In the case of TDMA we have to take care of this problem while scheduling transmissions.
Another problem is the exposed station problem, which means that two nodes (within each other's interference range, here nodes B and C) can send at the same time as long as their destinations are not in each other's interference range (nodes A and D in Figure 2, which are assumed to be outside of each other's interference range). Taking the exposed station problem into account while scheduling can lead to an increase in simultaneous transmissions.

2.5 CDMA-over-TDMA

CDMA (Code Division Multiple Access) is another medium access method for distributed networks. In this model, spread spectrum technologies are used to ensure a collision-free transmission even if several nodes send at the same time. The transmissions are encoded with special codes, so that the receivers can decode the messages (if they have access to the right codes) even if multiple nodes send at the same time. The main problem of CDMA is that the codes have to be distributed among the participating nodes. In a static network, this can be done easily. In ad hoc networks, on the other hand, this can be major problem, because it is not possible to distribute them manually. Therefore, there needs to be a mechanism that guarantees that all new nodes receive necessary codes.
In the CDMA-over-TDMA model, as described in [10,11], a CDMA mechanism is used on top of an underlying TDMA channel. In this model, when deciding the slot assignments along a route, only the one-hop neighbors of a node have to be taken into account. Devices still cannot send and receive at the same time, but there are no more problems like the hidden and exposed station.

3 Routing Protocols

The following section gives an overview over four different protocols for TDMA-based multicast-QoS-routing. As there are not many QoS multicast routing protocols for networks with pure TDMA, protocols assuming a CDMA-over-TDMA network model were also considered.

3.1 PSLCB

In the PSLCB protocol [15], the authors split the problem into two parts, routing and scheduling. At first, they focus on scheduling the transmissions into timeslots to achieve collision-free transmissions. To achieve this, they use a decentralized and heuristic algorithm that ensures that no nodes within the same local neighborhood schedule conflicting timeslots, taking into account the hidden and exposed station problem as well as the fact that communication and interference range are not necessarily the same. Furthermore, they use a routing algorithm that creates a tree structure with the destinations of a transmission as leafs, while minimizing the number of non-leaf nodes. Minimizing the number of non-leaf nodes is equivalent to minimizing the number of hops on the route, which can also be interpreted as the minimization of the global bandwidth consumption.

3.1.1 Interference-Aware Timeslot Assignments

A transmission from an arbitrary node A to an arbitrary node B is called interference-free if it does not collide with the transmission of any other node in the network. Keeping the hidden and exposed station problems in mind, the authors state the following theorem.

Theorem 1 *Sending from node A to B in timeslot t is interference-free iff*

- *A and B do not send / receive in t*
- *(all) neighbors of A do not receive in t*
- *(all) neighbors of B do not send in t*

Figure 3 shows the transmissions that, according to Theorem 1, are allowed in the same timeslot. For example, if node A sends to node B, then node C may only send to nodes outside of A's range and node D may only receive from nodes outside of B's range. Node C is not allowed to receive in slot t, as this would lead to a collision with the transmission from node A. Node D is not allowed to send in slot t, because this would lead to a collision in node B. There are two problems with this theorem. First, assigning slots to the whole route is an NP-hard problem. Furthermore, Theorem 1 assumes that the interference range of nodes is equal to the transmission range, which is usually not the case when using wireless communication. Therefore, another theorem is introduced.

Theorem 2 *A schedule is interference-free if no three consecutive links share the same timeslot.*

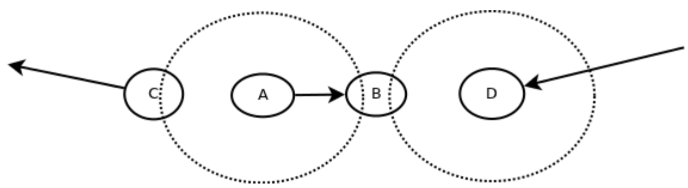

Figure 3: allowed concurrent transmissions

The optimal way to find a conflict-free schedule would be collecting information about the free timeslots of all nodes in the destination of a route and determining the schedule, for the whole route, in the destination node. However, this would be too time-consuming. So, a decision mode (**least conflict slot first**) is specified, which states that the slot with the least conflict with the next two links is selected first. For example, if there is a slot that is free in multiple nodes, this slot should not be scheduled for transmission until necessary because after selecting it is unusable for the next two links. This increases the chance of finding a conflict-free schedule.

3.1.2 Bandwidth aware QoS routing

As already mentioned, the goal of PSLCB is the minimization of forwarders along the route. Therefore, while creating the multicast tree, the number of non-leaf nodes of this tree is minimized. In this case, the number of non-leaf nodes is equal to the number of forwarders during the sending process. A multicast route fulfills a bandwidth requirement b if all links of the route have at least b interference-free timeslots. It is also assumed that data flows cannot split. In other protocols, as seen later, it is sometimes assumed that it is possible to split them in multiple parts and send them along different routes in order to increase the chance of finding a bandwidth satisfing route (**multipath routing**). This is not possible in this protocol.
The route setup starts when a new node wants to join an already existing multicast group. The joining node (here node D) prepares a JOIN packet which contains the following:

- s = source, the node that created the join packet
- b_req = bandwidth requirement
- $node\_list$ = list of nodes the packet has visited (initially D)
- $slot\_list$ = slot assignments
- TTL = (time to live) maximum hop limit until the packet is dropped

The packet is broadcasted to all neighboring nodes (Figure 4). When a node receives a JOIN packet, it checks whether it is already in the $node\_list$ of the packet. If this is the case, the node has already processed the packet and drops it. Otherwise, it reduces the TTL by one, checks if it can fulfill the bandwidth requirement and determines its own free slots. After that, there are two possibilities. If the receiving node is **not** part of the multicast group, it determines the slot assignments for the third previous link (and this link only) according to the rules in Section 3.1.1 (**least conflict slot first**). The packet is then forwarded to all neighbors (broadcast) (Figure 5 a)). If the node is already part of the multicast group, it determines the slot assignments for all three previous links and sends a REPLY packet back to the source node (Figure 5 b)). In both cases, the nodes wait until they have received a predefined number of JOIN packets and process the best one (shortest path according to the TTL).
The source can now collect REPLY packets. The REPLY packets contain the following values:

- s = id of the node that created the REPLY packet
- $node\_list$ = list of nodes the JOIN packet has visited

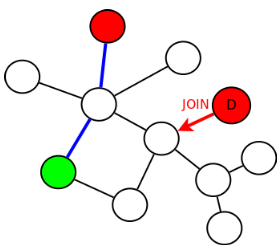

Figure 4: Node D broadcasts a JOIN packet

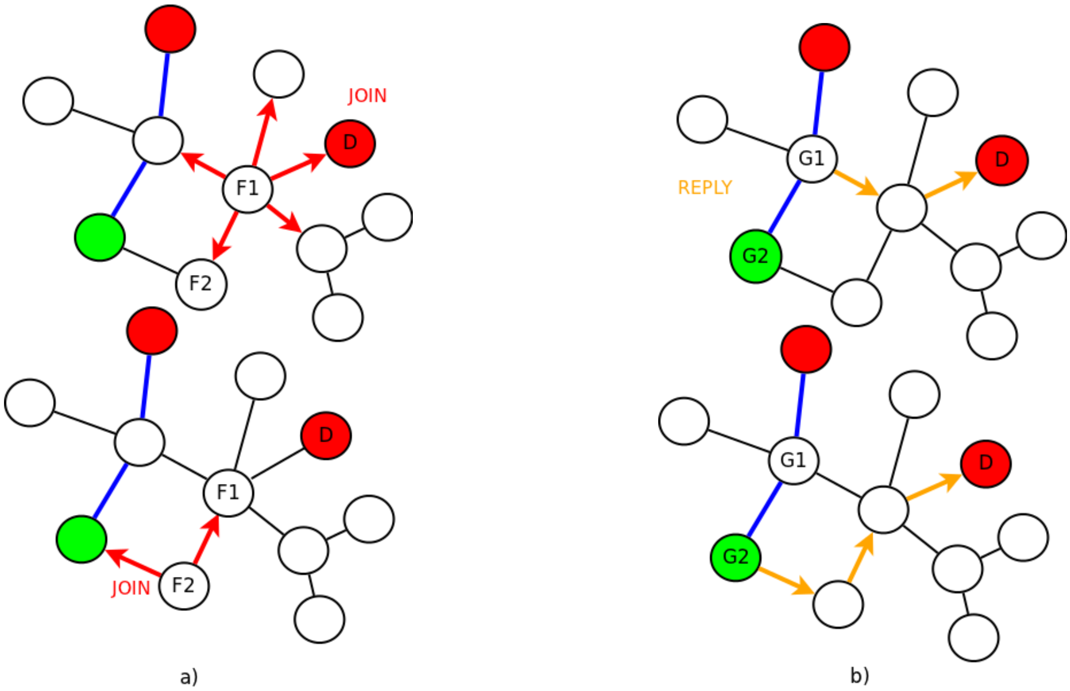

Figure 5: Nodes F1,F2 are not part of the multicast group (l.) and nodes G1,G2 are already part of the multicast group (r.)

The values from the REPLY packets represent various routes to different nodes of the multicast group. If the source, the node that originally created the join packet, selects the best of these nodes (the one with the shortest path), the resulting multicast tree is minimized considering the amount of non-leaf nodes. The source node then sends a RESERVE packet along the selected path and becomes part of the multicast tree. If no multicast group exists, the algorithm is initialized with the source, the node that wants to create a multicast group, and one of the destinations. Other destinations are subsequently added after the previous destination has been added to the multicast group.

3.1.3 Assessment

One advantage of this algorithm is, that it is designed for a network with a pure TDMA channel model. Also, the hidden and exposed station problems are taken into account in the rules for the timeslot assignments. Furthermore, the authors give simulation results. They compare their algorithm to the On-Demand Multicast Routing Protocol (ODMRP) [9] and show that it achieves a higher success rate and a lower end-to-end delay, but comes with a higher overhead compared to ODMRP. The fact that the interference range is (usually) greater than the communication range is mentioned, but the proposed solution does not really work. Figure 6 shows, that if the interference range is assumed to be twice the communication range and nodes A and B transmit in the same slot, a collision at node C would occur. According to Theorem 2, they would be allowed to transmit at the same time because the links are more than three hops away from each other. Another disadvantage of the protocol is that the only considered QoS-parameter is the bandwidth. Also, due to the assumption that flows cannot split, it is not possible to use multipaths to increase the chance of finding a

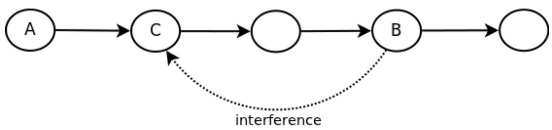

Figure 6: interference range vs communication range

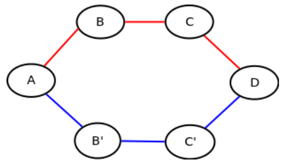

Figure 7: A hexagonal-block

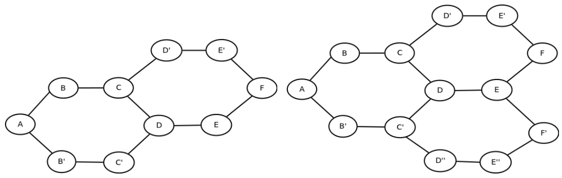

Figure 8: hexagonal twin (l.) and hexagonal branch (r.)

bandwidth-fulfilling route.

3.2 Hexagonal-Tree-Routing

In the Hexagonal-Tree-Routing protocol [5], a number of topology structures are introduced. The so-called hexagonal structures have several important properties, regarding multipathing and timeslot assigments. The routing protocol finds and combines those structures to form a multicast tree spanning the source and all destinations.

3.2.1 Hexagonal Structures

A group of six nodes is called a hexagonal-block if they build two parts from A to D and the "middle" nodes B and B' (C and C') are not in one-hop distance to each other (as illustrated in Figure 7). The hexagonal-block structure has several important properties. First, the structure forms a multipath (two-path) from one source to one destination, which increases the chance of finding a bandwidth satisfying route. So, for example, if all of the links in the block have only one free slot, but the bandwidth requirement is two, it is still possible to find a bandwidth-satisfying route. Another advantage of the structure is that the timeslots can be assigned according to fixed schemes. In Figure 7, link AB and link B'C' or link AB' and link BC can always share the same slots under the assumption that the interference range is the same as the communication range.

Other structures, called **hexagonal-twins** and **hexagonal-branches**, are also introduced. Figure 8 shows an example hexagonal-twin and hexagonal-branch, which are combinations of two resp. three hexagonal blocks. Those structures have similar advantages as the hexagonal-block. For example, in the hexagonal-branch data can be send along the sub-paths A B C D' E' F and A B C D E F as well as A B'C' D E F' and

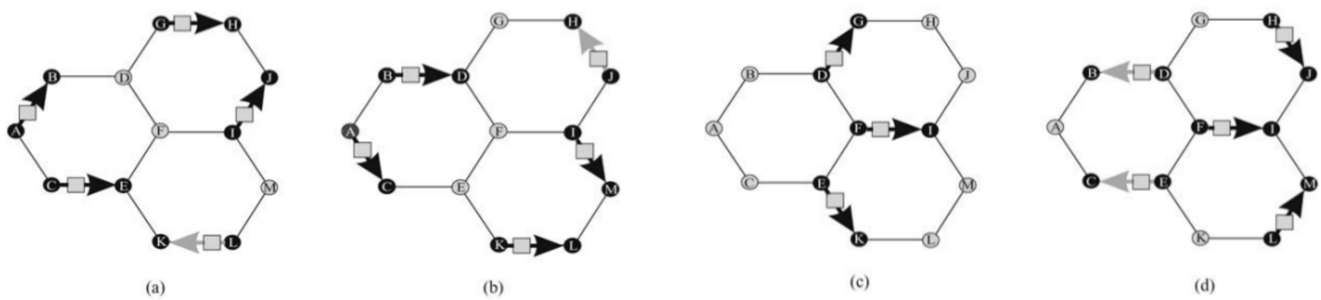

Figure 9: Timeslot reuse in a hexagonal-branch

A B' C' D" E" F' to deliver the data to two distinct destinations. They also allow scheduling according to fixed schemes. Figure 9 shows an example of links in a hexagonal-branch that are useable at the same time. In the example, the hidden and exposed station problems are taken into account, but it is assumed that the communication range is the same as the interference range.
Furthermore, **hexagonal-paths** are defined as paths (routes) that contain one or more hexagonal-blocks. A **hexagonal-tree** is a tree structure that contains at least one hexagonal-path.

3.2.2 Hexagonal-Tree-Routing

The first step of the routing process is the identification of hexagonal-blocks, hexagonal-twins and hexagonal-branches in the network. This is achieved by observing the one-, two- and three-hop neighborhood of nodes and saving sending and receiving activities of those nodes. For example, in a hexagonal-branch

$$\begin{bmatrix} & & & & G & H & \\ & B & D & & & & J \\ A & & & & F & I & \\ & C & E & & & & M \\ & & & & K & L & \end{bmatrix},$$

node F can collect information abouts its (up to) three-hop neighborhood and then construct the hexagonal structure and assign the timeslots as follows.
For a bandwidth requirement of b, up to $\frac{b}{2}$ identical slots are allocated to the links AB, CE, GH and IJ, which can all be used at the same time. In the next step, up to $\frac{b}{2}$ identical slots are allocated to another group of simultaneously usable links AC, BD, IM, and KL and so on... If in one step only $\frac{b}{2} - a$ with $a > 0$ identical slots can be scheduled on the links, another a distinct slots are scheduled. This continues until the scheduling is complete (all necessary links have $\frac{b}{2}$ reserved slots) or until the allocation is not possible in one step. In this case, no bandwidth satisfying-route can be found and the scheduling is aborted. If a working schedule is found, all links have reserved $\frac{b}{2}$ slots, so that the hexagonal-branch can fulfill a bandwidth requirement of b. In this case, the hexagonal-branch is successfully constructed. This works similar for the other structures.
In the second step of the routing process a hexagonal-tree, spanning the source and all destinations, is created. At first, the source searches hexagonal-paths between itself and the destinations. The source floods the network with hexagonal-path request packets to find a unipath that fulfills the bandwidth requirement. If no unipath can be found, it checks whether there is a hexagonal-block or if no hexagonal-block can be found, if there is a hexagonal-branch that can fulfill the requirements. The hexagaonal-path requests are relayed, in a similar manner, through the network until the destinations are reached or no path can be found.
The destinations reply to the request and send information about all hexagonal-paths to the source, which collects them. Now, the source can create the hexagonal-tree in a similar way as the spiral-fat-tree on-demand multicast (SOM) protocol [3] with the spiral-paths being replaced with hexagonal-paths. A spiral path P_k is a path where all nodes A are connected to their k-hop neighbor by an additional distinct link (Figure 10). The different paths are then merged to a tree according to merging criteria depending on the number, length and bandwidth of shared (parts of) hexagonal-paths to form the final hexagonal-tree.

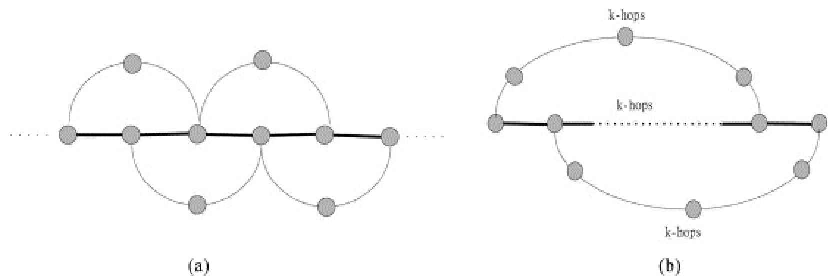

Figure 10: An example spiral-path with k = 2 (l.) and an arbitrary k (r.)

3.2.3 Assessment

The advantages of the presented protocol are, that it uses a TDMA network model and takes the hidden and exposed station problems into account (they are considered in the schemes for the timeslot assignments of the hexagonal structures). Also, multipaths (two-paths) are used to increase the chance of finding bandwidth-satisfying routes. The authors give simulation results, which compare their algorithm to AODV [12] and ODMRP [9] and show that the hexagonal-tree routing has a higher success rate and a lower latency than the two other algorithms, but also has a higher overhead. A downside is that they assume that the communication range is the same as the interference range and that the protocol only considers bandwidth as QoS-parameter.

3.3 Wu-Jia Routing

In the Wu-Jia Routing protocol [14] a CDMA-over-TDMA channel model is assumed instead of pure TDMA. On-demand flooding packets are used to find a description of the (partial) network topology from the source to the destinations. Furthermore, three different strategies are given (shortest path, least cost path, and multiple least cost path) to find a multicast tree for the found topology. The different strategies produce different results regarding bandwidth consumption and network cost of the routes.

3.3.1 Route Discovery

The first part of the protocol deals with the discovery of the (partial) network topology spanning the source and destinations. The source node floods the network with RREQ packets. These packets contain the following values:

- *source* = id of the source (of this packet)
- *destination-list* = set of destinations
- *seq-ID* = increasing sequence number
- *type* = packet type (here RREQ)
- *route* = routing information
- *freeslots* = free slots of visited nodes
- b = bandwidth requirement
- TTL = time to live

These values are used to uniquely identify the packet and save information about the route the packet has traveled. Nodes receiving a RREQ packet check if there is a free timeslot for the link from the last sender of the packet to itself. If there is no free slot, or the TTL is zero, the packet is dropped. Otherwise, the node updates the packet with its own information and resends it to its neighboring nodes. Additionally, if the node has already received this packet (determined by checking the source and seq-ID), it saves the information about the alternate route, but does not resend the packet.
After a pre-specified timeout or maximum number of received RREQ packets, nodes send a RREP packet to the source, containing information about all routes going through this node. The RREP packets contains the following values:

- *source* = id of the source of the RREQ packet
- *node-id* = id of the replying node
- *type* = packet type (here RREP)
- *route* = information about all paths to this node
- *freeslots* = information about frees lots of all nodes from all routes

- b = bandwidth requirement
- TTL = time to live

The source collects RREP packets and combines the information from these packets to an image of the network topology between itself and the destinations. This includes the bandwidth of all links (number of free slots).

3.3.2 Multicast tree creation

There are three different strategies to create multicast trees in the previously found network topology. The strategies aim not only at finding a bandwidth-satisfying route, but also at minimizing the network cost of a route. The cost of a path is defined as its bandwidth multiplied with the number of hops. The bandwidth of a path is the minimum bandwidth of the links in the path. The cost of a tree is defined similar.

SPTM

The first strategy is based on Shortest Path Tree (SPT) routing. SPT combines the shortest paths from the source to each destination to form the multicast tree. This strategy minimizes the delay. However, the found tree is not necessarily bandwidth-satisfying. The proposed solution, Shortest Path Tree based Multiple paths (SPTM), identifies path segments (concurrent parts of a path with the same bandwidth) that do not fulfill the requirements and finds alternative routes for those segments, such that the combined bandwidth of the paths fulfills the bandwidth requirements. Alternative paths with a lower delay are preferred. Due to the maximum TTL in the route discovery part, the alternative routes are still guaranteed to be below a certain delay.

LCTM

The second strategy, Least Cost Tree based Multiple paths (LCTM), finds a bandwidth-satisfying, delay-bounded tree while minimizing the network cost of that tree. It is based on Jia's algorithm [8] and works as described in the following. The procedure is initialized with the source. The source calculates to which destination it has the least cost path. This path is added to the (at the beginning empty) multicast tree. It then finds the destination with the lowest cost path to one of the nodes of the multicast tree and adds this path to the multicast tree. This is continued until all destinations are part of the tree. After that, the source identifies path segments that do not fulfill the bandwidth requirements and finds alternative paths for those segments similar to SPTM. Here, alternative paths with a lower cost are preferred.

MLCT

The third strategy, Multiple Least Cost Tree (MLCT), has the same aims as LCTM. LCTM uses a single "backbone" tree that is extended to fulfill the bandwidth requirements. If the "backbone" tree is not good, this can lead to a tree with a relatively high cost. Therefore, an alternative way of creating a bandwidth-satisfying, cost-minimizing tree is presented. The initial tree is created in the same way as with LCTM. The bandwidth requirement for all links is removed from the available bandwidth in the discovered network topology. Links that cannot fulfill the bandwidth requirement are removed completely from the description of the topology. Then this new topology is used to create a new multicast tree in the same way as with LCTM, until the combined bandwidth of all those trees can fulfill the QoS requirements.

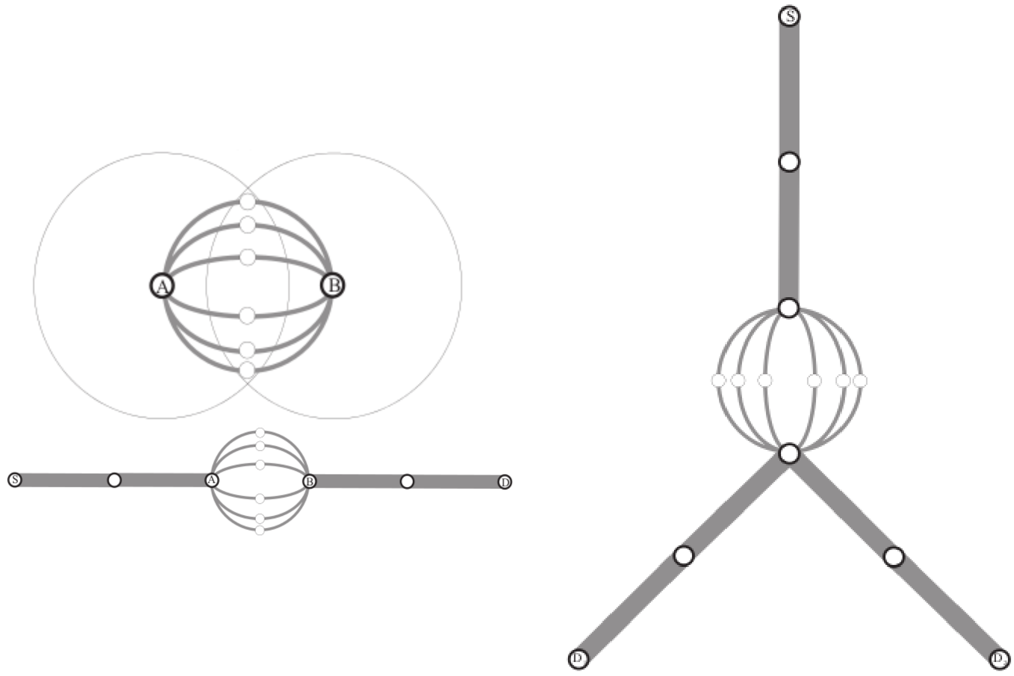

Figure 11: An example lantern, lantern-path and lantern-tree

3.3.3 Assessment

A disadvantage of this algorithm is, that it is designed to work with a CDMA-over-TDMA model. In this model, the hidden and exposed station problems, as well as the problem that the interference range is usually greater than the communication range, have to be addressed when assigning the codes for the CDMA mechanism. As the assignment of the codes is not covered in the paper, these problems are implicitly ignored.
An advantage is that multipaths are used to increase the chance of finding a bandwidth-satisfying route. Furthermore, this is the only examined protocol that offers another QoS-parameter besides bandwidth and provides routes that are delay bounded. Also, the authors give multiple strategies to optimize the routes depending on the context. The authors also provide simulation results. They compare the different strategies to a baseline least-cost-single-tree strategy and show expected improvements in the success rate and, depending on the used strategy, network cost. Unfortunately, they do not compare their algorithm to other protocols.

3.4 Lantern-Tree-Based QoS-Multicast Protocol

Like in the previous protocol, a CDMA-over-TDMA channel model is assumed in the Lantern-Tree-based QoS-Multicast protocol (LTM) [4]. A new structure, called lantern, is introduced in this protocol. The lantern is a flexible multipath structure. Several lanterns or uni-paths are combined to form a lantern-tree spanning the source and all destinations.

3.4.1 Lanterns

A group of nodes is called a lantern if they form one or multiple two-hop paths, with a combined bandwidth of B_r, from one source A to one destination B (Figure 11). Lanterns provide a flexible network structure based on the bandwidth of the links. If the links have a relatively low bandwidth, they form a multi path between two nodes. If the available bandwidth is high, they form a uni-path from one node to another. The

lanterns increase the chance of finding a route fulfilling a bandwidth requirement in a network with links that have a relatively low bandwidth available.
A path is called a **lantern-path** if one or more parts of the path form a lantern. Likewise, a tree is called a **lantern-tree** if it contains one or more lanterns. Figure 11 shows an example of a lantern, lantern-path and lantern-tree.

3.4.2 LTM: Lantern-Tree based QoS Multicast Protocol

The protocols finds and combines several lanterns to a lantern tree spanning the source and all destinations.

Phase 1: Lantern identification

The lanterns are found periodic beacon frames sent to the one- and two-hop neighbors of a node. With these beacons, the nodes maintain information about their local (two-hop) neighborhood. The maintained information includes the neighboring nodes as well as their free timeslots.
Let

$$\begin{bmatrix} & C & \\ A & D & B \\ & E & \end{bmatrix}$$

be a lantern, with AC, AD, AE and CB, DB, EB being one-hop links. In this case, AD and DB (AC and CB…) cannot share the same timeslot, because nodes may only send or receive in any timeslot. Likewise, AC, AD and AE (or CB, DB and EB) cannot share the same timeslot, because nodes may only send to or receive from a single node in one slot. Due to the CDMA-over-TDMA model, other links can share the same slots, e.g., AD and CB.

Phase 2: Lantern-path search

To find a lantern-path, the source node floods the network with lantern-path requests and checks if it is part of one or more lanterns. Lanterns can be one- or two-hop unipaths if the bandwidth of the links is sufficient. This operation is repeated by other nodes (that are path of the found lanterns) until the lantern-paths request reaches a destination node. If the bandwidth is sufficient for all links, the results of this algorithm are the same as the hop-by-hop reservation scheme [10, 11].

Phase 3: Lantern-tree construction

The lantern-tree construction is similiar to the spiral-fat-tree on-demand multicast (SOM) protocol [3]. Similar to the hexagonal-tree creation in section 3.2.2, the spiral-paths are replaced by lanterns and then merged together according to criteria related to the number, length and bandwidth of shared (parts of) lantern-paths. A tree maintenance mechanism is also given. If a subpath of the tree fails, a replacement from the local neighborhood is searched, so that the tree can be repaired.

3.4.3 Assessment

The proposed protocol makes use of flexible multipaths to increase the chance of finding and maintaining a bandwidth-satisfying route. The authors give simulation results, in which they compare their protocol to AODV [12] and ODMRP [9] and conclude that LTM has a better success rate while having more overhead. A disadvantage is that bandwidth is the only considered QoS-parameter. Like in the Wu-Jia routing protocol a CDMA-over-TDMA network model is assumed, which leads to the same simplifications of the timeslot assignments.

4 Conclusion

None of the protocols solves the problems of TDMA-based multicast QoS routing in mobile networks. A common drawback is ignoring that the interference range and the communication range of mobile nodes are not the same. Only one of the examined papers mentions this, and the proposed solution does not really solve all problems. The other protocols either do not mention this problem or make use of the CDMA-over-TDMA model, where this problem, as well as other problems, have to be considered when assigning the CDMA codes to the nodes.
Three of the presented algorithms use bandwidth as the only QoS-parameter. Bandwidth is probably the most common QoS-parameter, but having more options (like end-to-end delay or network cost in the Wu-Jia protocol) would be interesting. In many protocols multipathing is used to increase the chance of fulfilling bandwidth requirements. This is, in my opinion, a good solution. However it is only necessary / helpful when the available bandwidth is a limiting factor. More solutions with other QoS-parameters would be helpful.
The different strategies for the multicast tree creation seem to work well. This problem seems to be solved well in all of the protocols, even though the solutions are somehow similar in all of them.
Another big problem, often ignored, is the scheduling of control packets. All of the algorithms send a relatively large number of control packets, e.g., route requests and replies, which have to be scheduled, too. In other cases, the nodes have to observe their local neighborhood, which also requires a large amount of communication. This can lead to problems, due to collisions during the route creation process, which are not addressed by the protocols.

References

[1] Shigang Chen and Klara Nahrstedt. Distributed quality-of-service routing in ad hoc networks. *IEEE Journal on Selected Areas in Communications*, 17(8):1488–1505, 1999.

[2] Shigang Chen, Klara Nahrstedt, and Yuval Shavitt. A qos-aware multicast routing protocol. In *INFOCOM*, pages 1594–1603, 2000.

[3] Yuh-Shyan Chen, Tzung-Shi Chen, and Ching-Jang Huang. Som: Spiral-fat-tree-based on-demand multicast protocol in a wireless ad-hoc network. In *ICOIN*, pages 17–24, 2001.

[4] Yuh-Shyan Chen, Yun-Wen Ko, and Ting-Lung Lin. A lantern-tree-based qos multicast protocol for wireless ad-hoc networks. In Ronald P. Luijten, Eric Wong, Kia Makki, and E. K. Park, editors, *ICCCN*, pages 242–247. IEEE, 2002.

[5] Yuh-Shyan Chen, Tsung-Hung Lin, and Yun-Wei Lin. A hexagonal-tree tdma-based qos multicasting protocol for wireless mobile ad hoc networks. *Telecommunication Systems*, 35(1-2):1–20, 2007.

[6] J. J. Garcia-Luna-Aceves and Ewerton L. Madruga. The core-assisted mesh protocol. *IEEE Journal on Selected Areas in Communications*, 17(8):1380–1394, 1999.

[7] Anuschka Igel and Reinhard Gotzhein. An analysis of the interference problem in wireless tdma networks. In *ICWMC 2012, The Eighth International Conference on Wireless and Mobile Communications*, pages 187–194, 2012.

[8] Xiaohua Jia. A distributed algorithm of delay-bounded multicast routing for multimedia applications in wide area networks. *IEEE/ACM Transactions on Networking (TON)*, 6(6):828–837, 1998.

[9] Sung-Ju Lee, Mario Gerla, and Ching-Chuan Chiang. On-demand multicast routing protocol. pages 1298–1302, 2002.

[10] Chunhung Richard Lin. On-demand qos routing in multihop mobile networks. In *INFOCOM 2001. Twentieth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE*, volume 3, pages 1735–1744. IEEE, 2001.

[11] Chunhung Richard Lin and Jain-Shing Liu. Qos routing in ad hoc wireless networks. *IEEE J.Sel. A. Commun.*, 17(8):1426–1438, September 2006.

[12] C. Perkins, E. Belding-Royer, and S. Das. Ad hoc on-demand distance vector (aodv) routing, 2003.

[13] E. Royer and C. Perkins. Multicast Ad hoc On- Demand Distance Vector (MAODV) Routing, 2000.

[14] Huayi Wu and Xiaohua Jia. Qos multicast routing by using multiple paths/trees in wireless ad hoc networks. *Ad Hoc Netw.*, 5(5):600–612, July 2007.

[15] Xu Zhen and Zhou Long. Bandwidth constrained multicast routing for tdma-based mobile ad hoc networks. *Journal of Communications Systems*, 8(3):161–167, 2013.