Design and Implementation of Multi-Path Routing in Mobile Ad hoc Networks

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***Abstract*—Wireless Networking is an emerging technology that will allow users to access information and services regardless of their geographic position. In contrast to infrastructure based networks, in wireless Ad hoc Networks, all nodes are Mobile and can be connected dynamically in an arbitrary manner. All nodes of these networks behave as routers and take part in discovery and maintenance of routes to other nodes in the network. This feature presents a great challenge to the design of a routing scheme since link bandwidth is very limited and the network topology changes as users roam. This paper investigates the behavior of existing traditional routing algorithms and proposes and implements a new routing approach for Ad hoc wireless networks. The design and evaluation of multiple descriptions coding for multimedia transport over Mobile Ad hoc Networks. Instead of transporting data through a single communication pipe, the data is split up into multiple streams, which each take a different route through the network. This document explains the basics of Multi-path routing and provides an overview and comparison of Multi-path routing protocols which may be suited for the use of multiple description coding.**

***Index Terms*—MANET, ADHOC networks, MDC, AODV, AOMDV, DSR, ZRP, MSR.**

I. Introduction

A Wireless Ad-hoc Network is a collection of mobile nodes with no pre-established infrastructure. Each of the nodes has a wireless interface and communicates with others over either radio or infrared channels. Laptop computers and personal digital assistants that communicate directly with each other are some examples of nodes in an ad-hoc network. Nodes in the ad-hoc network are often mobile, but can also consist of stationary nodes. The topology of Ad-hoc Networks varies with time as nodes move, join, or leave the network. This topological instability requires a routing protocol to run on each node to create and maintain routes among the nodes. Routing is a function in the network layer which determines the path from a source to a destination for the traffic flow. A routing protocol is needed because it may be necessary to traverse several nodes (Multi-hops) before a packet reaches the destination. The routing protocol's main functions are the selection of routes for various source destination pairs and the delivery of messages to their correct destination. In wireless networks, due to host mobility, network topology may change from time to time. It is critical for the routing protocol to deliver packets efficiently between source and destination. Video or multimedia transport over wireless ad hoc networks is a challenging subject, since the wireless links are unreliable and have limited bandwidth. Typical multimedia applications, such as streaming, may require higher reliability connections than that provided by a single link. In a network consisting of mobile nodes, the connection between a source and destination may break down and has to be updated regularly. Although, when a path fails, one could switch over to an alternative path; thismay take an unacceptably long period of time, causing a temporary disruption in the multimedia signal. The design and evaluation of so-called multiple description coding (or compression) for multimedia transport over mobile ad hoc networks. Instead of transporting a multimedia stream through a single communication pipe, the stream is split up into multiple sub-streams, each of which takes a separate route through the network. At the destination all sub-streams received properly are merged in a clever way. The main idea behind Multiple Description Coding (MDC) is that each sub-stream provides enough information to recover the original signal with an acceptable quality. When more sub-streams are used for the recovery the quality of the recovered signal improves. A prerequisite to the study of multiple description coding is a thorough insight into the aspects of routing in mobile ad hoc networks. Unlike traditional protocols that will choose a single path through the network, the protocol(s) used for MDC must deliver multiple paths from a source to a destination. Also, the Quality of Service (QoS) aspects of each path (e.g. delay, bandwidth, and cost) must be taken into account paths that (presumably) cannot meet the QoS requirements imposed by the MDC must be eliminated. Finally, we expect that care must be taken that the different routes do not share nodes other than the source and destination nodes. To use a routing protocol in combination with MDC, it has to have certain properties. The protocol must provide multiple, loop-free, (preferably) node-disjoint paths from a source to a destination. Since multimedia streaming is wanted, the multiple routes need to be used simultaneously. Also the protocols cannot use a common clock (e.g. derived from GPS), because it is unavailable. The rest of the paper is organized as follows. Section 2 describes different classes of routing protocols for ad hoc networks. Section 3 discusses the principles of Multi-path as well as the use of Multi-path routing in combination with multiple description coding. Section 4 introduces a number of Multi-path routing protocols and section 5 compares these protocols and examines their suitability for MDC.

II. Taxonamy Of Routing Protocols For Ad Hoc Networks

A. Introduction

This section provides a short overview of the different

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aspects of routing protocols for Mobile Ad hoc Networks. Routing protocols are needed whenever delivered data packets need to be handed over several nodes to arrive at their destinations. Routing protocols have to find routes for packet delivery and make sure the packets are delivered to the correct destinations. Routing protocols for Ad hoc Networks can be classified into different categories according to the following criteria:

1) Pro-active, Re-active or Hybrid
2) Centralized or Distributed
3) Dynamic or Static

When a routing protocol is centralized, all decisions are made at a center node, whereas in a distributed routing protocol, all nodes cooperate, usually in a symmetric way, in order to reach a routing decision. A dynamic protocol may change behavior according to the network status, which can be congestion on a link or many other possible factors. A link may fail unexpectedly, or a new link may be added. A dynamic routing protocol must discover these changes, automatically adjust its routing tables, and inform other routers of the changes. The process of rebuilding the routing tables based on new information is called convergence. Static protocols on the other hand do not change when the network status changes, the changes must be added manually. An example of a static protocol is flooding; in which a node always retransmits an incoming packet, unless it already sent the same packet earlier.

B. Pro-active, Re-active and Hybrid protocol

Generally speaking, currently known routing protocols for ad hoc networks can be classified in three different classes: pro-active protocols, re-active protocols and the hybrid protocols. These three classes differ in a number of ways.

Pro-active protocols or Table-driven protocols, work in a way similar to wired networks they try to maintain an up-to-date map of the network, by continuously evaluating known routes and attempting to discover new ones. This way, when a path to a destination is needed at a node, or a packet needs to be forwarded, the route is already known and there is no extra delay due to route discovery. On the other hand, keeping the information up-to-date this way may require a lot of bandwidth, which is sparse, and battery power, which is limited in mobile ad hoc networks and even then information may still be out-of-date. The Distance-Vector protocols fall in the pro-active class.

Unlike pro-active protocols, Re-active protocols or On-demand protocols only start a route discovery procedure when needed. When a route from a source to a destination is needed, some sort of global search procedure is started. This does not require the constant updates being sent through the network, as in pro-active protocols, but it does cause delays, since the routes are not available and need to be found. In some cases the desired routes are still in the route cache maintained by nodes. When this is the case there is no additional delay since routes do not have to be discovered. Protocols such as DSR [1], [2] and AODV [3] are members of the re-active protocol class. Pure pro-active protocols are likely not fit for ad hoc networks where nodes move a lot, because of the high traffic overhead caused by continuously updating the network information. On the other hand, pure re-active protocols may also have their problems, extreme delays and excessive control traffic, may make them unfit for certain applications (e.g. real-time communication).

Hybrid protocols combine the advantages of both pro-active and re-active routing, by locally using pro-active routing and inter-locally using re-active routing. This is partly based on the assumption that most communication in mobile ad hoc networks takes place between nodes that are close to each other, and the assumption that changes in topology are only important if they happen in the vicinity of a node. When a link fails or a node disappears on the other side of the network, it has only effect on local neighborhoods; nodes on the other side of the network are not affected. The ZRP [4], [5], [6] is an example of a hybrid routing protocol. Table I show twelve Ad hoc routing protocols divided into the three classes.

TABLE I: TWELVE ROUTING PROTOCOLS DIVIDED INTO THREE CLASSES

Pro-active protocol	Re-active protocol	Hybrid protocol
OLSR OSPF TBRPF	AODV-BR AOMDV TORA MP-DSR ROAM SMR CHAMP MSR	ZRP

C. Basic Routing Protocol Families

1) Distance vector routing protocols

In distance vector routing protocols, every host maintains a routing table containing the distance from itself to possible destinations. Each routing table entry contains the next hop to the destination and the distance to the destination. Nodes only feed the estimated link costs for each destination (e.g. the number of hops to destination) to their neighbors, instead of flooding the whole network. All nodes calculate the shortest paths to the destinations using that broadcasted information.

2) Link state routing protocols

Link state routing protocols keep a routing table for complete topology, which is built up by finding shortest path of link costs. Link cost information is periodically transmitted and received by all nodes using a flooding technique; these periodic floods are called Link State Advertisements (LSA). Flooding means that a node sends out his information to all other neighbor nodes and they forward all received information to their neighbors and so on. Each node updates its table using the new link cost information gathered from these floods.

3) Source routing protocols

In source routing, all data packets carry their routing information as their header. The originating node could learn this routing information e.g. by means of a source routing protocol. When a node receives a (broadcast) route request packet for a destination it adds its own address to the header and then forwards the packet. The destination uses the recorded route in reverse order to send a route reply to the requesting node. Thus, the originating node is provided with the complete route to the destination. The routing decision is made at departure. Loops are avoided, since nodes can determine if they are already in the packet header.

III. Multipath Routing For MDC IN Mobile Adhoc Networks

For the use of multiple descriptions coding in ad hoc networks routing protocols need to have certain properties. This section first gives an explanation of Multi-path routing and then describes the requirements routing protocols must meet to support the use of MDC. Finally it briefly discusses the interface between the multiple description coding and the routing protocol.

A. Multi-Path Routing in Ad hoc Networks

Mobile Ad hoc Networks are characterized by a dynamic topology, limited channel bandwidth and limited power at the nodes. Because of these characteristics, paths connecting source nodes with destinations may be very unstable and go down at any time, making communication over ad hoc networks difficult. On the other hand, since all nodes in an ad hoc network can be connected dynamically in an arbitrary manner, it is usually possible to establish more than one path between a source and a destination. When this property of ad hoc networks is used in the routing process, we speak

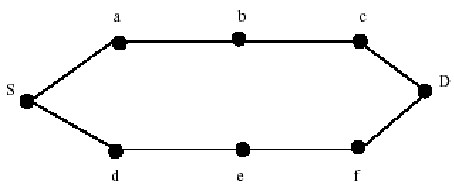


Fig. 3a. Two node-disjoint paths from source S to destination D.

Of multi-path routing. In most cases, the ability of creating multiple routes from a source to a destination is used to provide a backup route. When the primary route fails to deliver the packets in some way, the backup is used. This provides a better fault tolerance in the sense of faster and efficient recovery from route Failures multiple paths can also provide load balancing and route failure protection by distributing traffic among a set of disjoint paths. Paths can be disjoint in two ways: (a) link-disjoint and (b) node-disjoint. Node-disjoint paths do not have any nodes in common, except the source and destination, hence the do not have any links in common. Link- disjoint paths, in contrast, do not have any links in common. They may, however, have one or more common nodes (see Fig. 3).

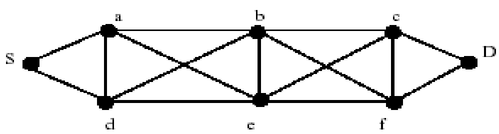


Fig. 3b. Two link-disjoint paths from source S to destination D.

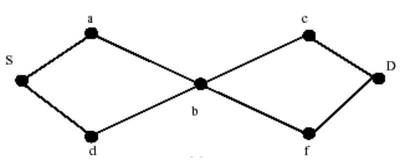


Fig. 3c. The two node-disjoint paths from fig. 3a, when they are in each other radio coverage

In order to use multiple paths simultaneously they need to be as independent as possible. So not only do they need to be disjoint, also route coupling [7] must be taken into account, because routes can interfere with each other. Route coupling takes place when a path crosses the radio coverage area of another path. There is a protocol that uses this property of radio broadcast to create backup-routes, but in the case of multiple-path data transport route coupling is unwanted. Routes may be link-joint or even node-disjoint but still interfere with each other due to route coupling. Consider the node-disjoint routes of figure 3a again. In the situation of figure 3c, when node *a* for example sends data to node b (both route 1), node *d* on the other route cannot transmit data to *e* on route 2, since the nodes (and thus routes) are in each others radio coverage area and interfere with each other. Since none of the routing protocols take the route coupling into account, we will ignore it in the sequel. Disjointness will be the only measure used for path independence.

B. Requirements for Multi-Path Routing with MDC in Ad hoc Networks

In our case we want to use multiple description coding (MDC) for multimedia transport over ad hoc networks. Instead of transporting a multimedia stream through a single communication pipe, the stream is split up into multiple sub-streams, each of which takes a separate route through the network. At the destination the different sub-streams are merged in a clever way, to recover the original stream. The main idea behind MDC is that each sub-stream received at the destination provides enough information to recover an acceptable representation of the original stream. When more streams are received, the quality of the recovered stream improves; the more streams received the better the quality of the recovered stream. This way of data transport requires the use of multiple (independent), disjoint paths from source to destination, which can be used to transport data simultaneously. When a routing protocol is needed for the purpose of using MDC in mobile ad hoc networks, certain properties are required. The described requirements are listed below:

- The routing protocol must provide multiple paths to destinations.
- The routing protocol must provide loop free paths to destinations.
- The routing protocol must provide node-disjoint paths to destinations, because (in this case) this is the strongest measure of path independence.

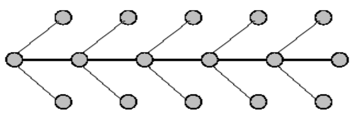
The multiple paths need to be used simultaneously for data transport, the MDC sub-streams need to arrive more or less simultaneously at the destination, so the multiple paths must not be backup routes, used only when the first route fails.

C. MDC-routing protocol interfaces

In order to use Multi-Path routing in combination with MDC some sort of interface is needed. The function of this interface is to control the interaction between the MDC-application and the routing protocol. It is possible to set up such an interface in different ways. The first possibility is letting the routing protocol determine routes according to a list of (QoS) demands. The main idea behind this way of setting up an interface is that the MDC-application sends a request to the routing protocol, in which the number of required paths from a source to a destination is specified, as well as the QoS demands for these paths (bandwidth, delay, cost). The routing protocol then tries to create these routes based on the QoS demands from the received request. When setting up the interface this way, problems might occur at the "lower-level" protocol-side of the interface. In situations where the routing protocol is not able to establish the required routes, it needs to make some sort of decision what to do next, should the request be discarded or should the best routes possible be presented (or something else) Because this decision should be made at the "higher-level" application-side of the interface, this first way of setting up the interface is perhaps not the best. The second way of setting up an interface between the MDC-application and the routing protocol works a bit different. In this case the application simply wants to know all possible routes from source to destination. The routing protocol passes on all available route-information to the MDC-application, which can then decide whether it wants to use a number of routes or not. The main advantage of this way of setting up the interface is that the "higher-level" MDC-application gets to decide if and which route(s) to use. So it is possible to adapt the coding to the available routes (e.g. when there is only one route available, the MDC-application could decide to use just that one, or when two routes are available and the application requires four, it could decide to re-encode the signal into two sub-signals).

III. Multipath Routing Protocols For Mobile Ad Hoc Networks

When exploring routing protocols for mobile ad hoc networks, a selection needs to be made in some way, in order to narrow down the number of protocols. In this paper, all protocols examined provide multiple paths from sources to destinations in some way. Some protocols simply provide partial backups of routes,



Others provide multiple complete routes from source to destination. Some specific solution of Multi-Path routing in below:

A. Ad hoc On-demand Distance Vector Backup Routing (AODV-BR)

Description:

The AODV-BR protocol uses the same route construction process as AODV [1]. When a source needs a route to a destination, and there is no route to that destination in its route cache, it searches a route by flooding a route request (RREQ) packet. Each of these packets has a unique ID so (intermediate) nodes can detect and drop duplicates. When an intermediate node receives a RREQ, it records the previous hop and the source node info and then broadcasts the packet or sends a route reply (RREP) packet back to the source if a route to the desired destination is known. The destination sends a RREP via the selected route when it receives the first RREQ or later RREQs that traversed a better route (with fewer hops).The alternate route creation part is established during the RREP phase, and uses the nature of wireless communications. When a node that is not part of the selected route overhears a RREP packet not directed to itself, it records the sending neighbor as the next hop to the destination in its alternate route table. In this way a node may receive numerous RREPs for the same route, select the best route among them and insert it into the alternate route table. When the RREP finally reaches the source of the route, a primary route between that source and destination has been established. All the nodes that have an alternate route to the destination in their alternate route table form a fish bone, as shown in figure 4a.

B. Ad hoc on-demand Multipath Distance Vector routing (AOMDV)

Description:

Like AODV-BR, the AOMDV [5] uses the basic AODV route construction process. In this case, however, some extensions are made to create multiple loop-free, link-disjoint paths. The main idea in AOMDV is to compute multiple paths during route discovery. It consists of two components:

- A route update rule to establish and maintain multiple loop-free paths at each node.
- A distributed protocol to find link-disjoint paths.

In AOMDV each RREQ, respectively RREP arriving at a node potentially defines an alternate path to the source or destination. Just accepting all such copies will lead to the formation of routing loops. In order to eliminate any possibility of loops, the advertised hop count is introduced. The advertised hopcount of a node i for a destination d represents the maximum hopcount of the multiple paths for d available at i. The protocol only accepts alternate routes with hopcount lower than the advertised hopcount, alternate routes with higher or the same hopcount are discarded. The advertised hopcount mechanism establishes multiple loop-free paths at every node. These paths still need to be disjoint. For this we use the following notion: When a node *S* floods a RREQ packet in the network, each RREQ arriving at node I via a different neighbor of *S,* or *S* itself, defines a node-disjoint path from I to *S*. (For proof see [5]).In AOMDV this is used at the intermediate nodes. Duplicate copies of a RREQ are not immediately discarded. Each packet is examined to see if it provides a node-disjoint path to the source. For node-disjoint paths all RREQs need to arrive via different neighbors of the source. This is verified with the firsthop field in the RREQ packet and the firsthop list for the RREQ packets at the node. At the destination a slightly different approach is used, the paths determined there are link-disjoint, not node-disjoint. In order to do this, the destination replies up to k copies of the RREQ, regardless of the firsthops. The RREQs only need to arrive via unique neighbors.

Properties:

- Extension of AODV.

- RREQs from different neighbors of the source are accepted at intermediate nodes.
- Multiple link-disjoint routes are created (with modification at the destination they can be node-disjoint).
- Maximum hop count to each destination ("advertised hopcount") is used to avoid loops.

C. Multi-Path Dynamic Source Routing (MP-DSR)

Description:

MP-DSR [8] is a QoS-aware multipath source routing protocol, based on Dynamic Source Routing protocol (DSR) [2], [9]. It is a fully distributed QoS protocol, which creates and selects routes based on a newly defined QoS metric, end-to-end reliability. The protocol seeks to compute a set of routes that satisfy a minimum end-to-end reliability requirement. Given a specific end-to-end reliability requirement, MP-DSR tries to discover multiple node-disjoint paths for data transmission, to satisfy such a requirement. The end-to-end reliability is defined as the probability of having a successful transmission between two nodes in the network within a defined period. First a brief explanation of DSR route discovery is given: When a host needs a route to a destination but no information is in its route cache, it will initiate a route discovery by flooding a RREQ packet throughout the network. A route record will be contained in the header of each RREQ in which the sequence of hops that the packet passes through is recorded. Any intermediate node contributes to the route discovery by appending its own address to the route record. Once the RREQ reaches the destination, a RREP will reverse the route in the route record of the RREQ and traverse back through this route. When an application wants to use MP-DSR for route discovery it supplies a minimum end-to-end requirement, based on which the protocol determines the number of paths needed (m0) and the lowest path reliability (Πlower) requirement that each path needs to provide. The relationship between m0 and Πlower is simple: when there are fewer paths between a source and a destination (m0 is low), more reliable paths are needed (Πlower is higher) to ensure the end-to-end reliability. When there are fewer paths between source and destination, more reliable paths are preferable and therefore Πlower is higher. Once these are determined, the source node sends out m0 RREQs, each of which contains information such as Πlower, the path traversed, the corresponding path reliability etc. When a node receives the RREQ message, it checks whether the message meets the path reliability requirement. If it does, the node will update the RREQ message (including itself in the traversed path and corresponding reliability) and forwards multiple copies of this message. The number of copies is based on the number of neighbors that can receive this RREQ without failing the path reliability, and also bounded by m0 to restrict the message forwarding in the network. When the destination receives the RREQ messages, it selects node-disjoint paths and replies RREP messages back along these disjoint paths. The source node in its turn starts sending data via the routes from which it receives the RREPs.

Properties:

- Source routing, so packets contain complete path (in header).
- Complete route information known at source.
- Provides multiple routes from source to destination.
- Provides node-disjoint paths.

D. Zone Routing Protocol (ZRP)

Description:

The Zone Routing Protocol (ZRP) [4], [5], [6] combines the advantages of pro-active protocols and re-active protocols in a hybrid scheme. It uses a pro-active protocol in the neighborhood of a node (Intrazone Routing Protocol, IARP) and a re-active protocol for routing between neighborhoods (Interzone Routing Protocol, IERP).

The local neighborhoods are called zones and are different for each node. Each node may be in multiple overlapping zones, which may all differ in size. The size of a zone is determined by a certain radius of lengthρ, and not by some geographical measurement. Where the length ρ is the number of hops to the perimeter of the zone. Obviously a node needs to know its neighbors before it can determine its neighborhood (routing zone) and its peripheral nodes. A Neighbor Discovery Protocol (NDP) is used for this. This, together with the earlier mentioned difference between local and inter-local routing, shows that the ZRP is not a distinct routing protocol, but more a framework for other protocols. For example a re-active protocol such as AODV [1] might be used as the IERP, while OLSR [3] can be used as the pro-active IARP. Figure 4.4a illustrates the different protocols and their interactions. The IARP in ZRP must be able to determine a node's neighbors itself, for situations where the NDP does not work. This protocol is usually a pro-active protocol and is responsible for the routes to the peripheral nodes.

Properties:

- Hybrid protocol (combining pro-active and re-active routing).
- No distinct protocol but framework.
- May or may not provide multiple paths (dependent of protocols used as IARP and IERP).
- Neighbor discovery through NDP.

E. Multi-path Source Routing (MSR)

Multipath Source Routing (MSR) [9], [10] is an extension of the on-demand DSR [2], [8] protocol It consists of a scheme to distribute traffic among multiple routes in a network. MSR uses the same route discovery process as DSR with the exception that multiple paths can be returned, instead of only one (as with DSR). When a source requires a route to destination but no route is known (in the cache), it will initiate a route discovery by flooding a RREQ packet throughout the network.

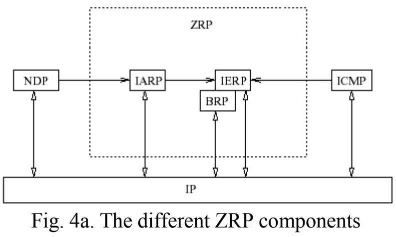


Fig. 4a. The different ZRP components

A route record will be contained in header of each RREQ in which the sequence of hops that the packet passes through is recorded. An intermediate node contributes to the route discovery by appending its own address to the route record. Once the RREQ reaches the destination, a RREP will reverse the route in the route record of the RREQ and traverse back through this route. Each route is given a unique index and stored in the cache, so it is easy to pick multiple paths from there. Independence between paths is very important in multipath routing; therefore disjoint paths are preferred in MSR. As MSR uses the same route discovery process as DSR, where the complete routes are in the packet headers, looping will not occur. When a loop is detected it will be immediately eliminated.

Properties:

- Re-active protocol (on-demand), extension of DSR.
- Provides multiple paths from source(s) to destination(s).
- Provides loop-free paths.
- Provides disjoint paths.

IV. Multipath Routing Protocol Comparison

	AODVBR	AOMDA	TORA	MPDSR	SMR	OLSR	OSPF	CHAMP	MSR
Multi-ple	N	Y	Y	Y	Y	N	P	Y	Y
Loop Free	Y	Y	Y	Y	Y	Y	Y	Y	Y
Node Dis-joint	N	P	P	Y	P	N	N	N	Y
Comp-lete	N	N	N	Y	Y	Y	Y	N	Y
Com-mon	N	N	Y	N	N	N	N	N	N
Delay	N	N	N	N	N	N	N	N	Y
Path used	N	P	P	Y	Y	N	N	P	Y
Implementation	A	A	T1	D	D	O	O2	N	D

Y=Yes, N=No and P=Possibly; A=AODV, D=DSR, T1=TORA, T2=TBRPF, O=OLSR and O2=OSPF

As described in section 3.2 a routing protocol must have certain properties, to be suited for the use of multiple descriptions coding in ad hoc networks. Here these properties are briefly

Mentioned. For a further explanation see section 3.2. In table 2 all earlier described Multi-Path routing protocols are compared with this list of requirements, with the exception of ZRP, the reason for this lies in the fact that the ZRP is a framework for other protocols. The ZRP is not a distinct protocol and thus will not be used in the comparison.

Protocol must provide multiple complete paths from source to destination.

AODV-BR, OLSR, OSPF and TBRPF do not provide multiple complete routes from source to destination and thus are not suited for the use of MDC. The AODV-BR only provides local backups; each node is able to direct traffic around a problem area (e.g. congestion at a node). With TBRPF all nodes have full topology information and could compute multiple paths to a destination, this is standard not the case however, only the minimum-hop paths are calculated.

Protocol should preferably provide loop-free paths.

All described protocols provide loop-free paths from sources to destinations. The source routing protocols, MP-DSR, SMR and MSR all have the complete routes included in the packet headers, so it is easy to detect and remove loops. In the case of AOMDV and AODV-BR it is done differently. AODV-BR uses sequence numbers to avoid loops, as is done in normal AODV, while AOMDV uses the notion of advertised hopcount to avoid loops. A different approach is used in TORA and CHAMP. They both use directed a-cyclic graphs to establish loop-free routes.

The protocol must provide node-disjoint paths.

Obviously AODV-BR, OLSR, OSPF and TBRPF do not provide node-disjoint paths, since these protocols are not able to provide multiple complete routes AOMDV and SMR do not always provide multiple node-disjoint paths. With AOMDV the paths could be node-disjoint, but only link-disjointness is guaranteed. A modification at the destination is needed to ensure node-disjointness in the paths. SMR provides two maximally disjoint paths. In other words, when node-disjoint paths are available it will provide them, but when only link disjoint paths are available, two link-disjoint paths will be provided.

The complete path information is known at the source.

The only protocols where complete route information is known at the source are the pro-active protocols, OLSR, OSPF and TBRPF, and the source routing protocols, MP-DSR, SMR and MSR. With AODV-BR and AOMDV, which are both distance vector protocols, only the next hop to the destination is known, with TORA and CHAMP this is also the case.

The delay of each path is known.

MSR is the only protocol that uses the delay of each path in some way. It uses the delay of each path to distribute traffic along these paths. This is done in such a way that paths with smaller delay will get more traffic. MSR is not the only protocol that uses a QoS metric in its routing process. As mentioned in section 4.4 MP-DSR also is a QoS-aware routing protocol. It introduces a new QoS measurement: end-to-end reliability, and uses that for creating and selecting routes.

The multiple paths are used simultaneously.

AOMDV, TORA, MP-DSR, SMR, CHAMP and MSR are the protocols that provide multiple complete paths from a source to a destination. In AOMDV, TORA and CHAMP there is only one route (mostly the shortest route) used for data transport, the others function as backups for when the primary route fails. MP-DSR, SMR and MSR the multiple routes are all used for data transport. The traffic originated at the source is split up and sent over different routes to avoid congestion and use resources more efficiently.

A basic implementation must be available

Due to the limited time of the CACTUS project, it is required that a basic implementation of the routing protocol exists. Fortunately this is the case for all described protocols. The AODV-BR and AOMDV protocol are based on AODV, for which there is a Linux implementation available. This implementation needs to be modified in order to function properly (AODV-BR: create backup routes and AOMDV: create complete multiple routes).For MP-DSR, SMR and MSR, all based on DSR, there is also a basic implementation available, a DSR implementation also in Linux. And just as for AODV-BR and AOMDV this implementation needs to be modified to support multiple paths and other properties. The implementations of OLSR, OSPF, TORA and TBRPF are also all available in Linux. These implementations do not need modification to function as described in section 4. However they need to be modified, because the protocols themselves are not able to meet the requirements for the use of MDC.

V. Conclusion

In order to use Multi-path routing for multiple descriptions coding in mobile ad hoc networks, a routing protocol is needed, which provides multiple complete loop-free routes from a source to a destination. These routes need to be as independent as possible, in this case node-disjoint, as they also need to be used simultaneously. These four requirements are only met by three of the earlier described routing protocols.

The Multi-Path Dynamic Source Routing protocol (MP-DSR), Split Multi-Path Routing protocol (SMR) and the Multi-Path Source Routing protocol (MSR) all provide multiple complete, loop-free, node-disjoint paths and are used simultaneous for traffic distribution. All the other protocols do not provide multiple complete, loop-free, node-disjoint routes, which are used simultaneously. MP-DSR uses a new Quality-of-Service (QoS) metric, the end-to-end reliability, to distribute the traffic along a number of paths. The number of paths is based on the required end-to-end reliability and is determined by the protocol itself. Therefore this protocol is not really suited for the use of MDC, since in that case the MDC-application wants to select the number of paths that will be used. SMR is a protocol which provides two maximally disjoint paths, one of which is the path with the shortest delay.

This protocol has the disadvantage that it provides “only” two paths and that they are “maximally” disjoint, which means that not always node-disjoint paths are found. The biggest disadvantage of SMR is the fact that the routes are selected at the destination. In our case we want to select the different routes at the source. This, together with earlier mentioned disadvantages makes SMR not suited for the use of MDC.MSR provides multiple complete, loop-free, node-disjoint routes from source to destination, which are used simultaneous to distribute traffic. This traffic distribution is based on the delay of the different paths in such a way that paths with lower delay get more traffic. This is the only property of MSR that needs to be modified for MDC, where the same amount of information is sent over different paths. Finally, it can be said that for the use of Multi-Path routing in combination with multiple description coding over ad hoc networks the MSR routing protocol is the best alternative. The only modification that needs to be made with this protocol is the way traffic is distributed. Normally in MSR the traffic is the distributed in a way that the paths with the shortest delay transfer the most data and paths with longer delay get less traffic, but in the case of multiple descriptions coding this is not wanted. With MDC each path used transports the same amount of information. Therefore the traffic distribution mechanism needs to be removed. Each path simply needs to transport the same amount of data traffic.

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