Mobile Ad Hoc Network Topology and its Algorithms

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Abstract **–** A Mobile Ad hoc Network (MANET) is an autonomous system of mobile nodes connected by wireless links. An important problem in is finding and maintaining routes since host mobility can cause topology changes. Several routing for MANETs are proposed which differ in the way new routes are found and existing ones are modified. MANET can be realized by different networks such as Body Area Network (BAN), Vehicular Ad hoc Network (VANET), Wireless Sensor Network (WSN). Wireless communication technologies such as Bluetooth, IEEE 802.11 and Ultra – Wide Band (UWB) can also be used for realizing MANETs. When each one of these networks combined with communication technologies pose various challenges in the design of algorithms. This paper discusses on the various algorithms for topology creation in MANETs.

Keywords **–** *MANET, BAN, VANET, WSN, UWB.*

I. INTRODUCTION

The design of algorithms for MANETs poses new and interesting research challenges, some of them particular to MANET. Algorithms for a MANET must self – configure to adjust to environment and traffic they run, and goal challenges must be posed from the user and application. Data communication in a MANET differs from that of wired networks in different aspects. The wireless communication medium does not have a foreseeable behaviour as in a wired channel. On the contrary, the wireless communication medium has variable and unpredictable characteristics. The signal strength and propagation delay may vary with respect to time and environment. Unlike a wired network, the wireless medium is a broadcast medium; that is, all nodes in the transmission range of a transmitting device can receive a message.

The bandwidth availability and computing resources are restricted in MANETs. Algorithms and protocols need to save both bandwidth and energy and must take into account the low capacity and limited processing power of wireless devices. This calls for lightweight solutions in terms of computational, communication and storage resources. An important challenge in the design of algorithms for a Mobile Ad hoc Network is the fact that its topology is dynamic. Since the nodes are mobile, the network topology may change rapidly and unexpectedly, thereby affecting the availability of routing paths. The following diagram represents MANET topology:

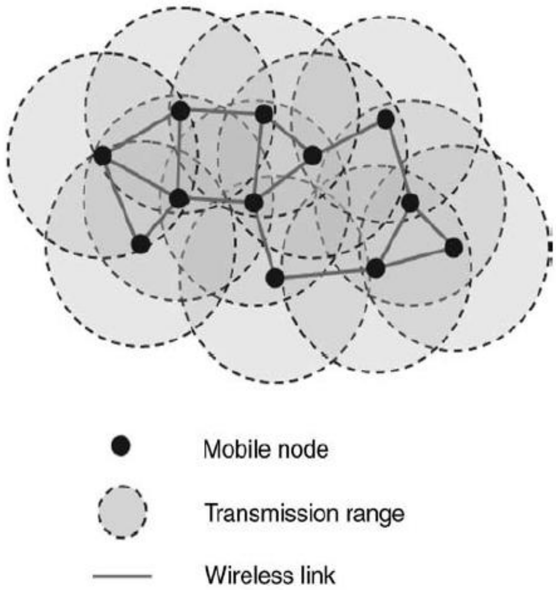

Figure 1.1: MANET topology

II. TOPOLOGY FORMATION

A. *Neighbour Discovery*

The performance of an ad hoc network depends on the interaction among communicating entities in a given neighbourhood. Thus, in general, before a node starts communicating, it must discover the set of nodes that are within its direct communication range. Once this information is gathered, the node keeps it in an internal data structure so that it can be used in different networking activities such as routing. The behaviour of an ad hoc node depends on the behaviour of its neighbouring nodes because it must sense the medium before it starts transmitting packets to nodes in its interfering range, which can cause collision at the other nodes. Node discovery can be achieved with periodic transmission of beacon packets or with promiscuous snooping on the channel to detect the communication activity.

B. *Packet Forwarding Algorithms*

An important part of a routing protocol is the packet forwarding algorithm that chooses the one to be used to forward the data packet among neighbouring nodes. The forwarding algorithm implements a forwarding goal that may be, for instance, the shortest average hop distance from source to destination. In this case, the set of potential nodes may include only those in direct communication range from the current node or also the set of possible nodes in the route to the destination. The forwarding goal may also include some QoS parameters such as the amount of energy available at each node.

The following forwarding algorithms consider only nodes that are in direct communication range of the node that has a data packet to be forwarded, as depicted in Figure 2.1. The Most Forward within Radius (MFR) forwarding algorithm chooses the node that maximises the distance from node S to point p. In this case, as depicted in Figure 2.1. It is node 1. On the other hand, the Nearest Forward Progress (NFP) forwarding algorithm chooses the node that minimises the distance from node S to point q. In this case, it is node 2. The greedy routing scheme (GRS) uses the nodes geographical location to choose the one that is very close to the destination node D. In this case it is node 3. The compass – selecting routing (COMPASS) algorithm chooses the node that minimises the angle α, but considers the nodes that are closer to node D. In this case it is node 4. The random process forwarding algorithm, as the name suggest, chooses a random node that is in direct communication range from S.

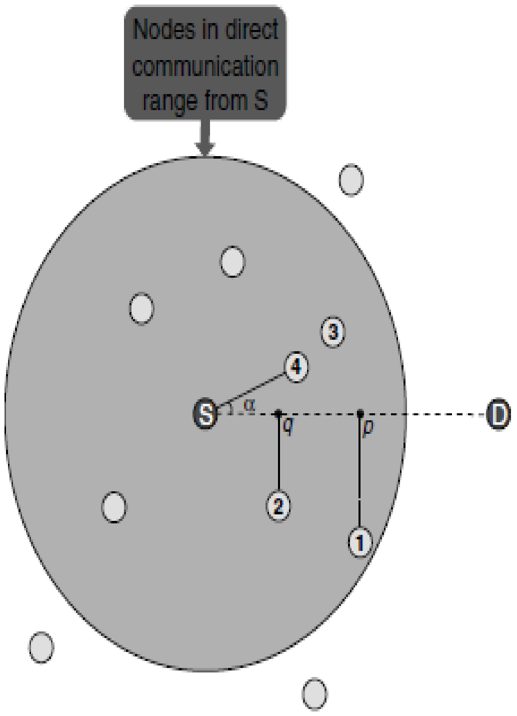

Figure 2.1: Strategies used by forwarding algorithms

The Partial Topology Knowledge Forwarding (PTKF) algorithm chooses a node using a localised shortest path weighted routing where routes are calculated based on the local topological view and considering the transmission power needed to transmit in that link.

III. TOPOLOGY CONTROL

Topology control algorithms select the communication range of a node, and they construct and maintain a network topology based on different aspect s such as node mobility, routing algorithm and energy conservation. Topology control algorithms for ad hoc networks can be classified in hierarchical or clustering organization, as well as in power – based control organization. These algorithms can be centralized, distributed or localized.

A. Clustering Algorithms

The clustering process consists in defining a cluster – head node and the associated communication backbone, typically using a heuristic. The goal is to avoid redundant topology information, so the network can work more efficiently. Clustering algorithms are often modelled as graph problems such as Minimum Connected Dominating Set (MCDS). This problem asks for the minimum subset of nodes V' in the original graph G= (V, E) such that V' form a dominating set of G and the resulting sub graph of the MCDS has the same number of connected components of G. It means that if G is a connected graph, so is the resulting sub graph. MCDS is an NP – complete problem and so we must look for approximate solutions. In the case of the clustering algorithm, nodes in the dominating set represent the cluster heads and the other nodes are their neighbours. An inherit characteristic of an ad hoc network, which makes this problem much more difficult is that its topology is dynamic.

The cluster heads can be elected using either deterministic of nondeterministic approaches. A deterministic solution is similar to a distributed synchronous algorithm in the sense that it run in rounds. In this case there is just one round, and after finishing it, the cluster heads are chosen. Suppose we have a node and its neighbouring nodes (one – hop neighbourhood node). The lowest ID solution selects the node with the lowest identifier among them to create the minimal dominating set (MDS). The max degree solution selects the node with the highest degree solution selects the node with the highest degree with them. The MOBIC solution examines the variations of RSSI (received signal strength indicator) signal among them to select the cluster head.

A nondeterministic solution runs multiple incremental steps to avoid variations in the election process and to minimize conflicts among cluster heads in their one hop neighbourhood. Examples are CEDAR, SPAN and solutions based on a spanning tree algorithm.

B. Power – Based Control Algorithms

A mobile node in a MANET must rely on an energy source to execute all its tasks. Batteries need to be charged to provide a continuous energy supply for a node. To extend the lifetime of nodes in an ad hoc network, algorithms are needed to determine and adaptively adjust the transmission power of each node so as to meet a given minimization goal, and at the same time to maintain a given connectivity constraint. Some possible minimization goals are to control the maximum or average power and define a maximum or average connectivity degree. Some connectivity constraints are simplex communication or full – duplex communication.

IV. ROUTING

The main goal of an ad hoc network routing algorithm is to correctly and efficiently establish a route between a pair of nodes in the network, so a message can be delivered according to the expected QoS parameters. The establishment of a route should be done with minimum overhead and bandwidth consumption. In the current wired networks, there are different link state and distance vector routing protocols, which were not designed to cope with constant topology changes of mobile ad hoc environments. Link – state protocols update their global state by broadcasting their local state to every other node, whereas distance – vector protocols exchange their local state to adjacent nodes only. Their direct application to a MANET may lead to undesired problems such as routing loops and excessive traffic due to the exchange of control messages during route establishment.

An ad hoc has a dynamic nature that leads to constant changes in its network topology. As a consequence, the routing problem becomes more complex and challengeable, and it probably is the most addressed and studied problem in ad hoc networks. This reflects the large number of different routing algorithms for MANETs proposed in the literature.

Ideally, a routing algorithm for an ad hoc network should not only have the general characteristics of any routing protocol, but also consider the specific characteristics of a mobile environment – in particular bandwidth, energy limitations and mobility. Some of the characteristics are: fast route convergence, scalability, QoS support, power, bandwidth and computing efficient with minimum overhead, reliability and security. Furthermore, the behaviour of an ad hoc routing protocol can be further complicated by the MAC protocol. This is the case of a data link protocol that uses a CSMA (Carrier Sense Multiple Access) mechanism that prevents some problems such as hidden stations and exposed stations.

In general, routing algorithms for ad hoc networks may be divided into proactive and reactive protocols that are discussed as follows:

A. Proactive Protocols

Proactive routing algorithms aim to keep consistent and up-to-date routing information between every pair of nodes in the network by proactively propagating route updates at fixed time intervals. Usually, each node maintains this information in tables, thus, protocols of this class are also called table-driven algorithms. Examples are: Destination – Sequenced Distance Vector (DSDV), Optimized Link – State Routing (OLSR) and Topology – Based Reverse Path Forwarding (TBRPF) protocols.

The DSDV protocol is a distance vector protocol that incorporates extensions to make its operation suitable for MANETs. Every node maintains a routing table with one route entry for each destination in which the shortest path route (based on the number of hops) is recorded. To avoid routing loops, a destination sequence number is used. A node increments its sequence number whenever a change occurs in its neighbourhood. When given a choice between alternatives routes for the same destination, a node always selects the route with the greatest destination sequence number. This ensures utilization of the route with the most recent information.

The OLSR protocol is a variation version of the traditional link state protocol. An important aspect of OLSR is the introduction of multipoint relays (MPRs) to reduce the flooding of messages carrying the complete link – state information. Upon receiving an update message, the node determines the routes (sequence of hops) to its known nodes. Each node selects its MPRs from the set of its neighbours such that the set covers those nodes that are two hops away. The idea is that whenever a node broadcasts a message, only those nodes present in its MPR set are responsible for broadcasting the message.

The Topology – Based Reverse Path Forwarding (TBRPF) is also a variation of the link – state protocol. Each node has a partial view of the network topology, but is sufficient to compute a shortest path source spanning tree rooted at the node. When a node receives source trees maintained at neighbouring nodes, it can update its own shortest path tree. TBRPF exploits the fact that shortest path trees reported by neighbour nodes tend to have a large overlap. In this way, a node can still compute its shortest path tree even if it receives partial trees from its neighbours. In this way, each node reports part of its source tree, called Reported Tree (RT), to all of its neighbours to reduce the size of topology update messages, which can be either full or differential. Full updates are used to sends the entire RT to new neighbours, to ensure that the topology information is correctly propagated. Differential updates contain the changes to RT that has occurred since the last update. To reduce further the number of control messages, topology updates can be combined with Hello messages, so that fewer control packets are transmitted.

B. Reactive Protocols

Reactive on-demand routing algorithms establish a route to a given destination only when a node requests it by initiating a route discovery process. Once a route has been established, the node keeps it until the destination is no longer accessible or the route expires. Examples of reactive protocols are Dynamic Source Routing (DSR) and Ad Hoc On – Demand Distance Vector (AODV).

The DSR protocol determines the complete route to the destination node, expressed as a list of nodes of the routing path, and embeds it in the data packet. Once a node receives a packet, it simply forwards it to the next node in the path. DSR keeps a cache structure to store the sources routes learned by the node. The discovery process is only initiated by a source node whenever it does not have a valid route to a given destination node in its route cache. Entries in the route cache are continually updated as new routes are learned. Whenever a node wants to know a route to a destination, it broadcasts a route request (RREQ) message to its neighbours. A neighbouring node receives this message, updates its own table, appends its identification to the message and forwards it, accumulating the traversed path in the RREQ message. A destination node responds to the source node with a route reply (RREP) message, containing the accumulated source route present in the RREQ. Nodes in DSR maintain multiple routes to a destination in the cache, which is helpful in case of a link failure.

The AODV protocol keeps a route table to store the next – hop routing information for destination nodes. Each routing table can be used for a period of time. If a route is not requested within that period, it expires and a new route needs to be found when needed. Each time a route is used, its lifetime is updated. When a source node has a packet to be sent to a given destination, it looks for a route in its route table. In case there is one, it uses it to transmit the packet. Otherwise, it initiates a route discovery procedure to find a route by broadcasting a route request (RREQ) message to its neighbours. Upon receiving a RREQ message, a node performs the following actions: checks for duplicate messages and discards the duplicate ones, creates a reverse route to the source node (the node from which the RREQ was received is the next hop to the source node), and checks whether it has an unexpired and more recent route to the destination (compared to the one at source node). In case those two conditions hold, the node replies to the source node with a RREP message containing the last known route to the destination. Otherwise, it retransmits the RREQ message.

V. MULTICASTING AND BROADCASTING

An important aspect in the design of a routing protocol is the type of communication mode allowed between peer entities. Routing protocols for MANET can be unicast, geocast, multicast or broadcast. Unicast is the delivery of messages to a single destination. Geocast is the delivery of messages to a group of destinations identified by their geographical location. Multicast is the delivery of messages to a group of destinations in such a way that it creates copies only when the links to the destinations split. Broadcast is the delivery of a message to all nodes in the network.

There are two types of physical transmission technologies that are largely used: broadcast links and point – to – point links. In a network with single broadcast channel, all communicating elements share it during their transmissions. In a network that employs a wireless medium, which is the case of a Mobile Ad Hoc network, broadcast is a basic operation mode whereby a message is received by all the source node's neighbours. In a MANET, the four communication modes implemented by a routing protocol are realized by a wireless broadcast channel.

A multicast routing protocol is employed when a mobile node wants to send the same message or stream of data to a group of nodes that share a common interest. If there is a geographical area associated with the nodes that will receive the message or stream of data, we use a geocast protocol. Thus, a geocast protocol is a special type of multicast protocol, such that nodes need their updated location information along the time of delivery of the message. In a multicast communication, nodes may join or leave a multicast group as desired, whereas in a geocast communication, nodes can only join or leave the group by entering or leaving the defined geographical region.

In MANET, a multicast communication can possibly bring benefits to the nodes such as bandwidth and energy savings. However, the maintenance of a multicast often based on a routing tree or mesh, is a difficult problem for mobile ad hoc multicasting routing protocols due to the dynamic nature of a MANET. In particular, the cost of keeping a routing tree connected for the purpose of multicast communication may be prohibited. In a multicast mesh, a message can be accepted from any router node, as opposed to a tree that only accepts packets routed by tree nodes. Thus, a multicast mesh is more suitable for a MANET because it supports a higher connectivity than a tree. The method used to build the routing infrastructure either tree or mesh in a mobile ad hoc network distinguishes the different multicasting routing protocols.

Some of the route – tree – based multicast protocols for MANETs are AMR (Ad hoc Multicast Routing) protocol, DDM (Differential Destination Multicast) and MAODV (Multicast Ad hoc On-Demand Distance Vector routing). AMR uses an overlay approach based on bidirectional unicast tunnels to connect group members into the mesh. DDM is a stateless multicast protocol in the sense that no protocol state is maintained at any node except for the source node. Intermediate nodes cache the forwarding list present in the packet header. When a route change occurs, an upstream node only needs to pass to its downstream neighbours the difference to the forwarding nodes since the last packet. MAODV is the multicast version of the AODV protocol. It uses a multicast route table (MRT) to support multicast routing. A node adds new entries into the MRT after it is included in the route for a multicast group. MAODV uses a multicast group leader to create an on-demand core-based tree structure.

Different from the previous route-tree-based multicast algorithms, LGT (Location Guided Tree Construction Algorithm for Small Group Multicast) uses the location information of the group members to build the multicast tree without the knowledge of the network topology. Two heuristics are proposed to build the multicast tree using location information: the Location-Guided k-array tree (LGK) and the Location-Guided Steiner tree (LGS).

Some of the mesh-based multicast routing protocols for MANETs are CAMP (Core-Assisted Mesh Protocol), FGMP (Forwarding Group Multicast Protocol) and ODMRP (On-Demand Multicast Routing Protocol). CAMP generalizes the notion of core-based trees introduced for Internet multicasting. It uses nodes for limiting the control traffic needed for the creation of multicast mesh avoiding flooding. On the other hand, both FGMP and ODMRP use flooding to build the mesh. In the FGMP protocol, the receiver initiates the flooding process, whereas in the ODMRP the sender initiates it.

VI. APPLICATIONS

Mobile ad hoc networks have been employed in scenarios where an infrastructure is unavailable, the cost to deploy a wired networking is not worth it, or there is no time to setup a fixed infrastructure. In all these cases, there is often a need for collaborative computing and communication among the mobile users who typically work as teams – for instance, medical personnel in a search and rescue mission, fire flighters facing a hazardous emergency, policemen conducting surveillance of suspects, and soldiers engaging in a flight. When we consider all these usual driving applications managed by specialized people, we understand why there is a slow progress in deploying commercial ad hoc applications to ordinary people.

This situation may change with the deployment of opportunistic ad hoc networks. These networks aim to enable user communication in an environment where disconnection and reconnection are common activities and link performance is dynamic. They are suitable to support the situation where a network infrastructure has limited coverage and users have "islands of connectivity". By taking advantage of device mobility, information can be stored and forwarded over a wireless link when a connection "opportunity" arises, such as an appropriate network contact happens. In this view, the traditional MANET incorporates the special feature of connection opportunity.

A MANET can be used to provide access to crisis management applications, such as in a disaster recovery, where the entire communication infrastructure is destroyed ad establishing communication quickly is crucial. By using a mobile ad hoc network, an infrastructure could be set up in hours rather than days or weeks, as in the case of a wired networking. One of many possible uses of a mobile ad hoc network is in noncritical and collaborative applications. One example is a business environment where the need for collaborative computing might be more important outside the office such as in a business meeting at the client's office to discuss a project. Another viable example is to use a mobile ad hoc network for a radio dispatch system. This system can be used, for instance, in a taxi dispatch system based on MANET. When a user wants to use an existing application on the Internet in a mobile ad hoc network, it is important to investigate its performance. This is the case, for instance, of Gnutella, one of the most widely used peer to-peer systems, which needs to be evaluated before putting it through typical ad hoc conditions such as node mobility and frequent network partitioning.

Another application area is communication and coordination in a battlefield using autonomous networking and computing. Some military ad hoc network applications require unmanned, robotic components. Unmanned Airborne Vehicles (UAVs) can cooperate in maintaining a large ground mobile ad hoc network interconnected in spite of physical obstacles, propagation channel irregularities, and enemy jamming. The UAVs can help meet tight performance constraints on demand by proper positioning and antenna beaming.

A vehicular ad hoc network (VANET) is a mobile ad hoc network designed to provide communications among close vehicles and between vehicles and nearby fixed equipment. The main goal of a VANET is to provide safety and comfort for passengers. To this end, a special electronic device is placed inside each vehicle that will provide ad hoc network connectivity for the passengers and vehicle. Generally, applications in a VANET fall into two categories, namely safety applications and comfort applications. Safety applications aim to provide driver's information about future critical situations and, hence, have strict requirements on communication reliability and delay. Some of the safety applications envisioned for VANETs are intervehicle dangerwarning, intersection collision avoidance, and work zone safety warning. Comfort applications aim to improve the driving comfort and the efficiency of the transportation system and, hence, are more bandwidth-sensitive instead of delay-sensitive.

Some of the comfort applications are on-board Internet access, high data rate content download (electronic map download/update), and driving through payment. With numerous emerging applications, opportunistic ad hoc networks have the potential to allow a large number of devices to communicate end-to-end without requiring any pre-existing infrastructure and are very suitable to support pervasive networking scenarios. For instance, suppose we want to (a) communicate with a mobile user who is temporarily out of reach or (b) establish a public wireless mesh that includes not only fixed access points but also vehicles and pedestrians, or interconnect groups of roaming people in different locations via the Internet. It seems that finally mobile ad hoc networks and Internet are coming together to produce in the next few years viable commercial applications.

CONCLUSION

A mobile ad hoc network is one of the most innovative and challenging areas of wireless networking and tends to become increasingly present in our daily life. An ad hoc network is clearly a key step in the next-generation evolution of wireless data communication when we consider the different enabling networks and technologies.

An ad hoc network inherits the traditional problems of wireless and mobile communications, including bandwidth optimization, power control, and transmission quality enhancement. In addition, MANETs pose new research problems due to the multihop nature and the lack of a fixed infrastructure. These problems are related to algorithms for different aspects such as network configuration, topology discovery and maintenance, and routing. The problems in ad hoc networks face a very important and fundamental question that is the dynamic network topology. This has a serious impact on the design of algorithms for ad hoc networks since they are expected to work properly under different and unpredictable scenarios. Similar to other distributed problems, a designer can start reasoning about an algorithm for this type of network, initially considering a static version of the problem. In a static version, it is reasonable to assume that there is a global topological information of the network, the computation happens just once, and the proposed solution is a centralized algorithm.

On the other hand, when we consider a dynamic solution for the same problem, it is reasonable to assume that there is only local information, the computation happens continuously along the time the network is operational, and the proposed solution is a distributed algorithm. Clearly, the dynamic solution is more useful for ad hoc networks. However, a detailed study of the static solution tends to provide valuable insight for the design of a distributed version, is useful to determine the upper bound on the performance of the algorithm, can even be applied to stationary ad hoc networks such as commercial mesh-based broadband wireless solutions, and is simple to understand.

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