Routing Protocols and Metrics used on Wireless Mesh Networks

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Abstract—Wireless Mesh Networks (WMNs) have an abundant number of routing protocols, some sources suggested that more than 70 protocols may exist. The existence of so many protocols can be attributed to the lack of standards which would define its operations. In this work we categorise and discuss the inner workings of proactive, reactive and hybrid routing protocols. Our discussions lead us to determine a few aspects that if already aren’t should part of the design paradigm for routing protocols designed for WMNs.

Keywords - Routing Protocols, Metrics, Wireless mesh networks, design

I. INTRODUCTION

Wireless local area networks (WLAN) serve as alternatives to wired networks. A WLAN is a data communication system implemented as an alternative for a wired LAN. Using radio waves, in the unlicensed portion of the spread spectrum, WLANs transmit and receive data over the air.

The IEEE 802.11 family of standards, also known as WiFi, is currently the most successful wireless networking standard for wireless LANs [1]. This standard is virtually synonymous with the term WLAN today [2] [3]. In this family the IEEE 802.11b has become one of the world’s most popular wireless networking standard, so much so that it is the most prominent standard found on wireless network cards. The ones that are commonly found on wireless cards are the 802.11 a, b, g and n.

These wireless cards are the hardware that allow any wireless device (running the same standard – IEE802.11) to connect to any other device within range of its radio signal. Once connected these wireless devices (which we shall call nodes) form a wireless blanket or cloud. The problem, however, is that the cards do not provide a means for information in the form of a data packet to travel from a node at one end of the blanket to a node at the other end. Packets can only travel to their nearest (within radio range) neighbour. In order for all nodes to be able to communicate we need to add routing functionality.

Routing can be understood as the process of driving packets from source nodes to destinations node in a network. Routing is therefore probably the most important part of wireless network architecture [4] as everything else depends on it for communication and this is what we explore in this work.

This work is structured as follows, in section II we go further into what a routing protocol is and associated path selection. Section III discusses the more prominent routing protocols designed for WMNs while sections IV discusses the routing metrics. Finally in section V we conclude.

II. ROUTING

We deal with wireless mesh networks which are a type of packet switching networks. In packet switching networks, the routing protocol directs packet forwarding which as mentioned in the previous section is the transit of packets from their source toward their ultimate destination through intermediate nodes. There are an abundant number of routing protocols for these types of networks some sources say over 70 exist. Each protocol is known to use a routing strategy. The routing strategy can be generalized so that we can group protocols with similar strategies together in categories. The two main categories are the proactive and reactive routing protocols.
Proactive routing protocols are also known as non-adaptive (static routing) and are characterised by none adaptive networks where the routes are pre computed and the topology is either static or slow changing.

Reactive routing protocols are also known as adaptive (dynamic routing) and are characterised by a dynamic network topology which affect routing decision which are made on demand (as roots are needed). Hybrid is another category that is in a combination of the two, either leaning more towards proactive or reactive.

There are other routing strategies that can also be generalized and groups formed. There is the alternative routing and multipath routing which is based on random decision or network state (changes all the time) respectively. Then there is the distributed strategy where network information is received form adjacent neighbours used to determine routes. This one is contrasted with the centralized strategy based on master and slave idea, master slave determines routes a slave without an associated master is unable to route its traffic.

These routing strategies produce routing protocols that are in principle different but are similar as they try to achieve one or a combination of these desirable properties [4]:

- robustness - algorithm needs to cope with networks changes (topology traffic changes)
- stability
- fairness - often a trade off with optimality
- optimality - often a trade off with fairness
- throughput
- load balancing
- congestion control

Each protocol chooses which of these properties it will focus on as some like fairness and optimality tends to be tradeoffs.

The process of forwarding packets from one node to another through intermediate nodes – routing – is only part of the process. To be more precise it is only the final part of the entire process. Remember that in wireless links there can be more than one path from source to a destination. Choosing the most appropriate path for the packet is called path selection.

### A. Path Selection Metric

Path selection is a process that selects one path from a list of possibilities as part or as the whole route for a packet to its destination. This process involves applying a routing metric to multiple routes, in order to select (or predict) the best route. A metrics is a property of a route consisting of any value used by routing algorithms to determine whether one route should perform better than another. A metric can include information such as [5]:

- bandwidth,
- network delay,
- packet loss rate,
- hop count,
- path cost,
- load,
- reliability,
- and communication cost
Other metrics are built upon techniques that may include other metrics such as the ones mentioned above. The added sophistication of the metrics facilitates the selection of better paths. All in all these metrics serve to represent the link cost between two nodes in the network. Some of the most popular metrics used for WMNs are:

- Expected Transmission Count (ETX) [6] [7] – which is the loss rate of broadcast packets between pair of nodes.
- Round Trip Time (RTT) – This is the round trip delay between pair of nodes.
- Hop Count – This is the number of links between pair of nodes.

### III. ROUTING PROTOCOLS

We shall now dive into the protocols themselves and explore the problems each protocol has tried to solve and how it has or has not accomplished its goals. We will reviewing each protocol in an endeavour to understand what makes all the protocols different from each other and finally proposing paradigms to serve those that will design routing algorithms for wireless mesh networks in the future.

A good starting point is to try and understand the reason why there are so many routing protocols. This question is addressed by Kowalik, K. and Davis, M [7]. The authors say that the primary reason for this is the lack of a standard which would define its operations. Even though the IEEE 802.11 is a set of standards which define many aspects of the functioning of WMNs currently there is no accepted standard for routing. This leaves the various aspects of the functioning of WMNs open to public debate and many subsequent solutions to this problem. This is a view also supported by Abdalla A.H. et al [8]. The authors also mention another important reason for the abundance of routing protocols for WMNs. This reason being the range of applications for this technology. By this the authors mean that mesh technology finds many applications in disaster recovery, building automation, campus connectivity, military communication, municipal networks, etc [9]. Such applications can have diverse operational requirements such scalability (large area of access), security (secure communication), QoS (QoE- quality of service and experience respectively). All of these are in essence the reasons for the existence of the desirable properties of routing protocols we mentioned in section II.

Campista, M.E.M. et al [10] serves as a qualifier for the second reason being the primary one. The authors mention that the existence of so many routing protocols is due to the various ways of utilizing the wireless medium and combinations of existing and new ideas. The different ways to use the medium give the protocols their inherent nature. This nature is composed of the desirable properties aforementioned.

Having covered the reasons for the existence of so many routing protocols we now proceed to investigate and review the prominent routing protocols used for WMNs.

Srikanth, V. et al [4], review a few routing protocols, stating what they are classified as. Remember that there are three primary classifications mentioned earlier in this work and these are reactive, proactive and hybrid. Srikanth, V. et al [4] details as part of reactive protocols, Adhoc on Demand Distance Vector(AODV), Dynamic Source Routing(DSR), SRCRR, Link Quality Source Routing(LQSR), Multi radio LQSR(MRLQSR). As part of proactive protocols, Optimized Link State Routing (OLSR), Destination Sequence Distance Vector (DSDV), Scalable routing using heat protocols. Finally as part of hybrid protocols
MeshNetworks Scalable Routing (MSR). Here we present the details of each protocol. First are those classified as reactive routing protocols.

**DSR-dynamic source routing:**
The source will check in its route cache whether there is a valid route to the destination. If there is a route, the source uses this route. If there isn’t the source then generates a route request packet. The host which receives the route request will perform the following operations:

- If the request id for the route request is found in this host’s list of recently seen requests, then it discards the route request packet.
- If the request identification (ID) for the route request is found in this host’s list of recently seen requests, then discard the route request packet and do not process it further.
- If the pair initiator address, request id for the route request is found in this host’s list of recently seen requests, then discard the route request packet and do not process it further.
- Otherwise, append this host’s own address to the route record in the route request packet, and rebroadcast the request.
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An advantage of this protocol is that it does not require any periodic beaconing so the node can conserve power making it suited for low powered devices. However its shortcomings are that it has no mechanisms for handling congestion from high traffic load. Not scalable as delay increases with network size.

**AODV – Ad hoc on Demand Distance Vector:**
It is interesting to note that in context to ad hoc wireless network: In Latin, ad hoc literally means "for this", further meaning "for this purpose only" and thus usually temporary [11]. Routes are set up on demand, and only active routes are maintained. This reduces the routing overhead, but introduces some initial latency due to the on demand route setup. It uses a simple request-reply mechanism for route discovery very similar to that of DSR. The advantages of this protocol is that it reacts quickly to the topology changes and is loop free and avoids count to infinity problem. However it also has shortcomings such as, no routes are set up on demand, and only active routes are maintained. This reduces the routing overhead, but introduces some initial latency due to the on demand route setup. Also it is not suited for low powered devices. Furthermore packet delivery ratio drops dramatically when the number of connections increases.

**SrcRR:**
Is an extension of DSR using the ETX metric. It mainly deals with throughput by considering link loss and transmission bit-rate and transient bursts. When a node wants to send a data to a node for which a path is not know then the same process as DSR and AODV is followed accept with one added feature. The node that receives a route request packet appendes the ETX metric from the node from which it received the request. To ensure only fresh information is used for routing, if a link metric has not been updated within 30 seconds it is dropped from the link cache. The advantage of this protocol that it finds routes with high throughput rates. The down side is that it is not scalable due high number of query traffic.
LQSR- Link Quality Source Routing:
Like SrcRR it is an extension of DSR by adding some metrics to DSR. The metrics are HOP: shortest-path routing closest to SR, RTT: round-trip time latency, PktPair: packet-pair latency, ETX: expected transmission count. The advantage of this protocol is that it increases throughput since it considers the ETX metric. Its shortcomings are the same as its metrics. Some of these metrics are HOP: shortest-path routing closest to SR, RTT: round-trip time latency, PktPair: packet-pair latency, ETX: expected transmission count and overhead as the metrics use probe packets.

MR-LQSR:
It is based on using a metric called Multi-radio (MR) with LQSR. The assumption is that if a node has multiple radios, they are turned to different, non-interfering channels. The protocol uses the link weights to find a good path for a given destination. Its advantages are similar to those found when using multiple radios: load balancing, trade off between delay and throughput as it considers channels with good quality. The disadvantage is that it is not scalable.

We continue with the protocols classified as proactive:

DSDV- destination-Sequenced Distance Vector routing:
Each node in the network keeps K: the node’s age, periodically incremented. H: the set of its current neighbours. In general, the message includes age and length of each node in the network in a nodes routing table. To reduce this traffic, routing table updates can be sent in two ways: a full dump (spread across many packets) or an incremental update (only bit of the routing table that have changed, done one packet). The advantage of this is that DSDV guarantees loop-free paths and higher efficiency in route discovery as opposed to the latency experience in reactive protocols. The disadvantage is delivery ratio decreases with network size. Also network resources are unnecessarily consumed when the network is stable and congestion control is worst.

OLSR- Optimized Link State Protocol:
It is an optimization version of a pure link state protocol. topological changes cause the flooding of the topological information. To reduce the possible overhead in the network protocol uses Multipoint Relays (MPR) by reducing the same broadcast in some regions in the network. There are two types of control messages, HELLO (finding hosts and link status), Topology control (TC- used to broadcast list of MPR selectors as well as own advertised neighbours). TC is broadcasted periodically by MPR hosts, only. The advantage is that it is best suited for dense networks where the source and destination keeps changing constantly. The disadvantages are that bandwidth is wasted on TC messages aggravated by increasing network size.

Scalable routing using heat protocols:
The gateways in the network are modelled s heat sources which create a temperature field in the network. The higher the temperature of a node, the closer it is to an access point. packets are forwarded along the nodes with the highest temperature until they eventually reach any heat source; for instance and internet gateway. Te key idea of HEAT is to provide scalability (with regard to protocol overhead) and robustness (with regard to link and node failures). Whenever an entry is added, removed, or changed, he temperature value is re-computed. The advantage is scalability with less resource consumption and ease of routing. The disadvantage is that external environment heat can affect the gateways. Unnecessary power consumption during some load balancing may also affect the heat parameter of a node.
The paper concludes that Scalability is most challenging factor that has to be considered in all the protocols that have been used till now. Selecting an effective protocol for a network requires one to look at the behaviour of the protocol in various conditions thus no one specific protocol is better than the other. A protocols performance in s WMN depends on the network its self.

Mahmod, Z.S et al [8], further extends the list of classified protocols for MWNs with a few protocols it believes are worth mentioning. They start with Reactive hop-by-hop routing (AODV-CGA). AODV is a reactive routing protocol which means that a route to another device is created on demand by flooding route requests using an expanding ring search mechanism AODV-CGA is an extension to standard AODV proposed by Braun et al [12], to support gateway discovery in mesh networks. All gateways are connected to a devoted router that acts as a proxy to the Internet which initialises and sends route replies for nodes in the mesh. AODV does not have to distinguish between the different gateways and only route to the dedicated router.

Next the authors mention the pro-active Field Based Routing (FBR): The idea of FBR is that mobile devices chose one of their neighbours as default gateway where all the packages are sent to.

Finally gateway source routing (GSR) is mentioned but it is not quote clear if it is a pro-active or a reactive protocol. It reuses the forward path (the intermediate hops) information from the packets-headers that arrive at the gateways (then stored there). To route packets to a mesh node, the mesh gateway inverts the recorded forward path. However, this approach requires the traffic to be unidirectional from a gateway toward a mesh node.

Similarly to Srikanth, V. et al [4], Mahmod, Z.S et al [8] concludes that protocols can use different methods to compute the paths, distribute the routing information and update these. Routing not only needs to match the radio environment but also it needs to be adapted to a specific application.

Campista, M.E.M. et al [10], attempt review ongoing research on WMN routing and analyze WMNs routing protocols then propose a taxonomy based on the algorithms. The first distinction the authors make when speaking about routing protocols is which routing category it falls in. A protocol can either be pro-active, reactive or hybrid. These have been explained in section II. The authors then take it one step further and propose their taxonomy (classification) of the routing protocols for WMN.

These classes are ad-hoc-based, controlled-flooding, traffic-aware and opportunistic. Each differs on how route discovery and maintenance is performed. One critical problem of wireless networks is the fast link-quality variation. The ad-hoc-based routing protocol class are adapted ad hoc protocols to deal with link-quality variations in WMNs. An example given is the link quality source routing (LQSR) protocol. It combines link-state proactive routing with the reactive approach found in ad hoc networks. This makes it a hybrid protocol in nature. Another example is the SrcRR which was created by the MIT Roofnet project [13]. It is loosely based on Dynamic Source Routing (DSR) and the ETX metric. They both implement route discovery procedures using source routing and the ETX metric.

Next the authors had the controlled-flooding:
These use algorithms designed to reduce control overhead generated from routing updates floods through the network. The basic assumption made is that flooding since communications in WN are between nearby nodes flooding is inefficient. The authors say that the common approach is to use algorithms which find the minimum set of nodes needed to forward routing information to all destinations in the network. An example is the localized on-demand link state (LOLS) assigns costs to links. The short term costs represent the current cost of a link which are frequently sent to neighbours. The long term costs represent the usual link costs and are sent using longer periods. LOLS uses the ETX metric to compute routes. Another commonly known routing protocol for WMN that falls in this class is the Optimized link state routing (OLSR) which was adapted to use ETX as a link metric.

Continuing the authors had the traffic-aware or tree-based protocols: These consider a tree-like network topology. An example is the ad hoc on-demand distance vector-spanning tree (AODV-ST) adapts the AODV protocol. The AODV-ST supports ETX metric.

Finally the authors had the Opportunistic protocols: It improves classical routing based on cooperative diversity schemes. These schemes exploit the broadcast nature of radio-frequency transmission to set multiple paths towards a destination. The receiver requires suitable transceivers to choose one of the relayed signals or to use a combination of them. An example is the Extremely Opportunistic Routing (ExOR) protocol [14]. It broadcast packets in batches (reduces protocol overhead) with no previous route computation. The down side is that it does not guarantee that packets are received, because they are not acknowledged.

We cannot see the added benefit behind further classification of WMN routing protocols as proposed by Campista, M.E.M. et al [10]. In our opinion, all the taxonomy does is create further groupings and not offer any further insight on the WMN routing protocols then existing ones.

The works we have reviewed above, for the most part, seeked to explain the inner working of each protocol by categorising them and in some cases further grouping them. These protocols are all similar in their approach at designing and performing routing in WMNs. Any differences between members of groups are due to design decisions influenced by the needs of the designers of the protocols and or the network the protocol is designed for. The next few examples show another approach to designing and performing routing in WMNs.

Kone V and Das, S [15] take an existing protocol designed and that works well for ad hoc networks and adapts it for WMNs. The authors study the performance of AQOR (Ad hoc QoS On-demand Routing Protocol) and it variant for WMNs, known as WMR (Wireless Mesh Routing) a QoS enabled routing protocol for wireless mesh networks. The outcome is the WMESH routing protocol that adapts to the WMN architecture.

The WMESH routing protocol provides quality of service (QoS) guarantees from source to destination specifically, the route selected by the protocol should provide the minimum bandwidth requested by the application and the end to end latency should not exceed allowed maximum. WMESH deals with three metrics (bandwidth, delay and stability) whereas AQOR only deals with the first two metrics. Stability is defined as a percentage value of received HELLO packets with respect to the expected number of HELLO packets in the last interval.
The simulation of WMESH and AQOR was done. The performance of the protocols is also compared with non QoS aware AODV to show its effectiveness. Preliminary simulation results show that WMESH performs significantly better than AQOR and AODV in terms of packet delivery ratio, control overhead and end to end latency. This may serve as proof that adaptation of this nature may serve WMNs better than expected.

Another approach is called Cross-layer routing and is covered by Iannone L, et al [16]. As reasoning for cross-layer routing the authors argue that routing algorithms be it proactive, reactive or hybrid do not take into account the interference they produce on a certain region of the network when they use a certain path to transmit packets. Each time a node transmits a packet the immediate neighbours must refrain from accessing the channel and others observe a reduction in their performance due to higher interference.

In order to achieve globally higher network throughput capacity, the interference generated on each hop has to be limited as much as possible and this is a trade-off between transmission power and interference generated.

The objective in the cross-layer approach is to provide the routing layer with an overall view of the MAC and PHY parameters and information. By breaking the separation between layers, the authors believe that they might turn physical or link layer drawbacks into advantages, allowing full access to the benefits that wireless network may bring. This will help in finding paths that are reliable and efficient. Therefore the authors propose a cross layer approach that uses a new triple-metric (rate, interference, Interference and Packet Success Rate-PSR), as perceived at the PHY-Layer, in order to maximize global throughput capacity.

Iannone L, et al [16] found that in their approach the network layer is able to set parameters of the physical layer, namely the transmission power, on a per hop basis; in order achieve a global power optimization and throughput improvement. Also compared to QoS routing which use parameters at network layer it offers more control of the lower layers.

We have reviewed the routing protocols their design differences and inner workings, we now take a look at the routing metrics that assist the routing protocols in the path selection process.

**IV. EXISTING ROUTING METRICS**

As mentioned in the Section II, routing metrics are used in conjunction with routing protocols and for the most part can be can be used in different protocols. Routing metrics compute route weights or values that are then used by the protocol in its route decision making process. Here we present a few routing metrics that are prominent in literature.

Draves, R et al [17], study the performance of three link-quality metrics, and compares their performance to that of each other and the minimum hop-count routing metric.

The first metric is called “Expected Transmission Count” ETX). It is a calculated value between zero and one based on the ratio of forward and reverse transmission counts. The metric’s overall goal is to choose routes with high end-to-end throughput. It is the predicted number of data transmissions required to send a packet over a specific link including retransmissions. The ETX of a route is the sum of the ETX for each link in the path [6]. ETX
has a few short comings: it does not distinguish links with different bandwidths nor consider data packet sizes. This is overcome by the Expected Transmission Time (ETT) metric [10] [17].

The second metric is called “Per-hop Round Trip Time” (RTT). This metric is based on measuring the round trip delay seen by unicast probes between neighbouring nodes [17]. The third metric is called “Per-hop Packet Pair Delay” (PktPair). This metric is based on measuring the delay between pair of back-to-back probes to a neighbouring node.

The authors discovered that on a static network the ETX metric out performs the hop count and the RTT and PkPair metrics. The RTT metric gives the worst performance among the four metrics. This is due to the phenomenon of self-interference. The RTT metric uses far more paths per connection than other metrics and suffers from self-interference on all hops along the path. The PktPair metric performs better than RTT, but worse than both HOP and ETX also due to self-interference.

Interesting to note that in a mobile scenario hop-count performs better as it reacts quickly to fast topology changes brought about by the dynamic environment; however, in a more static environment such as the one found in WMNs it performs poorly.

A routing algorithm can select better paths by explicitly taking into account the quality of wireless links. Each of these metrics represents a different notion of what constitutes good link quality whether it is low the loss rate, bandwidth, throughput, etc.

Couto, D.S.J.D. et al [6], goes further into the comparison of ETX and the minimum hop-count metric. ETX finds the best links in terms of throughput and despite losses while minimum hop-count finds best links in terms of shortest number of hops.

The use of minimum hop-count as metric has drawbacks. Some of these drawbacks are that the metric only sees two types of links, ones that works and ones that don't. In wireless networks there is are varying degrees of link quality in this case measured successfully delivered packets. So a link that delivers 50% of its packets would be classified as loopy and discarded by such metrics but may still serve to deliver network information packets to nodes. Furthermore, minimizing hop-count maximizes the distance between the hops which then incurs other problems such as being more prone to interference and minimized signal strength increasing the loss rate. ETX on the other hand picks paths that minimize the packet loss rates. However these issues are tied to distance between nodes so surely if the nodes are close enough that distance is not relevant then the metric performs well. The authors say that under that condition the minimum hop-count metric is not likely to select the best links.

Draves, R et al [17] suggests that minimum-hop count is outperformed by ETX but may still serve as good metric for WMNs since it outperformed other metrics. However, Couto D.S.J.D. et al [6] revealed that minimum-hop count is not a suitable metric for WMN and is best suited for more dynamic environments such as those found in ad hoc wireless networks.

**V. CONCLUSION**

In this work we have reviewed prominent routing protocols and metrics designed to assist these protocols. We have seen how the design choice used in the algorithms helps to classify them and the algorithms used help to further group these. We have seen that the strengths and weaknesses of the protocols are dependent on the type of WMN and scenarios of use.
Having seen all of this we can conclude with what believe are design paradigms that should be looked at when a routing protocol for WMN is made.

A. Design Paradigms

In summary, routing not only needs to match the radio environment(such as rural areas, with its own issues, or urban areas, metropolitan areas -radio interferences) but also it needs to be tailored to a specific application [7]. The mechanisms used to gather routing information, store it and compute paths based on metrics must be carefully combined to obtain stable routing performance. The design of a routing protocol is therefore a recipes where the designers have to carefully pick and take into account:

- The performance requirements of the application
- The radio environment
- Path selection metrics
- The technology
- Size of the network

The corrected selection of these components can lead to the design of a routing protocol that constructs good paths. A good path is one which is able to effectively transport data with reasonable delay, throughput and reliability [16].
REFERENCES


