Wireless Mesh Routing Protocols For Health Communication Systems[1]

Aggeliki Sgora and Dimitrios D. Vergados

University of the Aegean
Department of Information and Communication Systems Engineering
GR-832 00, Karlovassi, Samos, Greece
email: {asgora; vergados}@aegean.gr

Abstract

Wireless Mesh Networks (WMNs) consist of mesh routers and mesh clients. Mesh routers have minimal mobility and form the backbone of WMNs, while mesh clients can be either stationary or mobile, and can form a client mesh network among themselves and with mesh routers. WMNs are characterized by dynamic self-organization, self-configuration and self-healing to enable flexible integration, quick deployment, easy maintenance, low cost, high scalability and reliable services. WMNs may be also used to improve the performance of multi-hop ad-hoc networks, Wireless local area networks (WLANs) and Wireless Metropolitan Area Networks (WMANs). One of the factors that influence the performance of WMNs is the routing protocol that is used. Many routing protocols for WMNs can be found in the literature. However, not all these protocols are suitable for health communication systems. In this paper, based on the operational requirements of the health applications, we classify several routing protocols for wireless mesh networks and highlight their advantages and performance issues when they are used in healthcare.

Keywords: Wireless Mesh Networks, Routing Protocols, Health Communication Systems.

1. Introduction

Wireless communications are in rapid development and promise great opportunities to improve health care. A promising solution for wireless health environments is wireless mesh technology. A Wireless Mesh Network (WMN), as described in [Akyildiz et al. (2005)], is a multi-hop wireless network in which each node can communicate directly with one or more peer nodes. A WMN consists of mesh routers and mesh clients. Mesh routers have minimal mobility and form the mesh backbone for mesh clients. Mesh clients can be either stationary or mobile, and can form a client mesh network among themselves and with mesh routers.

---

[1] This work has been supported by GSRT, Hellenic Ministry of Development and co-funded by European Social Fund (75%) and National Resources (25%), through the PENED 2003 project "Design and Development Models for QoS Provisioning in Wireless Broadband Networks".

WMNs are characterized by dynamic self-organization, self-configuration and self-healing to enable flexible integration, quick deployment, easy maintenance, low cost, high scalability and reliable services, and may also be used to improve the performance of multi-hop ad-hoc networks, WLANs and WMANs. WMNs can also provide wireless Internet connectivity at lower cost than the classic WiFi networks. Several companies, such as Firetide [Firetide Inc] and Motorola [Motorola Company] are developing their proprietary WMN IP solutions. Moreover, several IEEE working groups have established their own task groups to develop their mesh standards with coverage ranging from PAN to MAN [Lee et al. (2006)], as it can be seen in Table I.

One of the factors that influence the performance of WMNs is the routing protocol that is used. Therefore, the choice of the routing algorithm in a wireless mesh network is critical and should be further investigated. Many mesh routing algorithms may be found in the literature. The main reasons for this are the lack of a standard, which would define its operation, the diversity of the range of applications for this technology and the diversity of the operational requirements of each application [Kowalik et al. (2006)].

For example, health communication systems have different requirements than broadband conventional communications. In this paper, we study the applicability of the WMNs routing protocols in healthcare. More specifically, we investigate the way that they may be implemented in the health environment as well as their advantages in terms of availability, reliability, QoS support and latency.

The paper is organized as follows: Section II overviews the benefits from the use of WMNs in the wireless health networks. Section III presents several well-known wireless mesh routing protocols that are already used by several commercial WMN products or in many academic projects. Section IV presents the operational requirements of the health applications, the application scenarios. Section IV examines the applicability of wireless mesh routing protocols in healthcare. Finally, Section V concludes the paper.

Table 1. *Wireless Mesh Standards*

Types of Mesh Technology	IEEE Specification
WPAN mesh	802.15.5
WLAN mesh	802.11s
WMAN mesh	802.16a

2. WMNs and Healthcare

The significant characteristics of the WMNs make them ideal for a number of health applications that cannot be directly supported by other wireless networks, such as cellular networks, ad hoc networks, standard 802.11 etc [Akyildiz et al. (2005)].

Moreover, there are many benefits of using WMNs in a health environment. These benefits include:

- Coverage Expansion: WMNs can expand the coverage of indoors and outdoors networks: from the doctor's desk to the ambulance bay; between multiple buildings; or for temporary uses such as in connecting mobile diagnostic units to hospital radiology labs.
- Mobility Support: In WMNs, connectivity is available to emergency vehicles that are moving at high rates of speed, making the early diagnosis by a specialist in an emergency vehicle reality. This could result in a faster patient recovery period and reduced medical errors.
- High data rates communication: WMNs can support high data rates up to 6 Mbps. Therefore, wireless mesh networks can ensure the high integrity transmission of data, even high resolution medical images, and the periodical monitoring patients' status.
- Broadband Access: WMNs can easily provide high-speed Internet access as well as connectivity for any medical equipment- without running miles of cabling. As a sequence, clinical teams can use wireless-enabled laptops and other handheld computing devices to access the hospital's internal network, patient records, Internet, e-mail, file sharing and other applications.
- Location Tracking: WMNs offer built-in ranging and positioning capabilities that can be used to locate personnel and assets. This capability is built-in, and does not rely on GPS satellites. Therefore, location tracking can be very helpful for finding people with matching blood groups or the required medical equipment, locating organ donors, helping old and mentally challenged people in hospitals, nursing homes and identifying a staff member within a specific speciality closest to an emergency location.
- Quick and easy connection: WMNs are easily deployed and connect related offices and facilities surrounding the main medical campus, such as diagnostic facilities, research labs, out-patient facilities, pharmacies, the offices of doctors who have hospital privileges on-site, community-based care organizations, and related social services offices.

3. Wireless Mesh Routing Protocols: Overview

The mesh routing protocols that are already used by several companies for their commercial products or in several academic projects can generally be classified into three categories: proactive, reactive and hybrid protocols. Proactive (or table-driven) routing protocols collect information in advance such that it will be available when need arises. Therefore, each node maintains a full routing table for all destinations and routing updates are used in order to maintain up-to-date information.

Reactive (on demand) routing protocols, on the other hand, look for information only when needed. For example, when a node needs to reach another node, routes are dynamically created as a result. Hybrid routing protocols: Some of the nodes may implement a proactive routing protocol and others a reactive routing protocol.

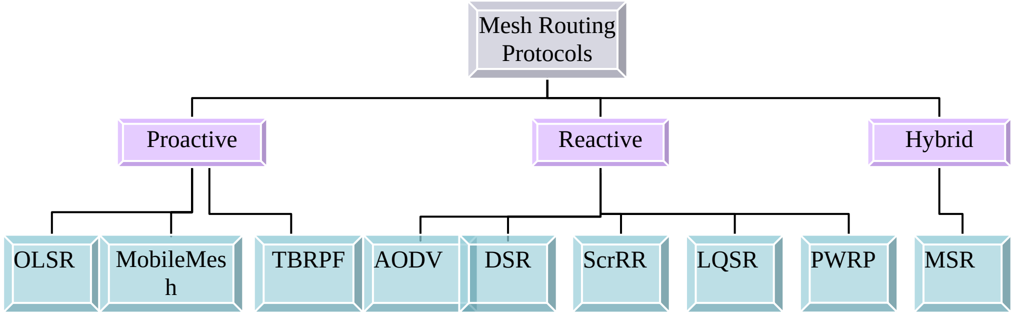

Figure 1. *Routing Protocols Classification*

3.1 Proactive Mesh Routing Protocols

3.1.1 Optimized Link State Routing Protocol (OLSR)

Optimized Link State Routing Protocol (OLSR) is a proactive routing protocol developed initially for mobile ad hoc networks [Clausen et. al. (2003)]. OLSR adapts the multipoint relay (MPR) concept. MPRs are a minimal set of one-hop neighbors such that all two-hop neighbors are reachable through these MPRs. The protocol uses the MPRs to facilitate efficient flooding of control messages in the network. In OLSR, only MPRs are responsible for forwarding control traffic intended for diffusion into the entire network. MPRs provide an efficient mechanism for flooding control traffic by reducing the number of transmissions required. OLSR is currently the preferred mesh networking protocol in the SeattleWireless project [Seattle Wireless Project].

3.1.2 Topology Broadcast based on Reverse-Path Forwarding (TBRPF)

TBRPF [Ogier et al. (2004)] is a proactive protocol that provides hop-by-hop routing along shortest paths to each destination. Each node running TBRPF computes a source tree (providing paths to all reachable nodes) based on partial topology information stored in its topology table, using a modification of Dijkstra's algorithm. Each node periodically broadcasts part of its source tree to its neighbors as an update. These updates are not further forwarded but may cause a change in the receiving node's source tree that is again propagated in the next update message. Differential updates are used to minimize the overhead. Neighbor sensing is realized with hello messages, which are broadcasted to give information about changes taking place in the neighborhood topology. Each node is also able to report additional topology information to improve robustness in order to support highly mobile networks.

TBRPF is used commercially in Firetide brand mesh network routers [Firetide Inc].

3.1.3 MobileMesh Routing Protocol (MMRR-Mobile Mesh)

MobileMesh Routing Protocol (MMRP) is a proactive routing protocol developed by the Mitre Company [Mitre Corporation]. MobileMesh contains three separate protocols, each addressing a specific function [Mitre Corporation]

- *Link Discovery*: The MobileMesh Discovery Protocol (MMLDP) is based upon a traditional "Hello" message that is broadcasted periodically by its interface.
- *Routing:* The MobileMesh Routing Protocol (MMRP) builds least-cost paths between any source and destination nodes. This information is contained in the "Link State Packet" (LSP) packet. To enhance scalability, a technique called fish-eye routing is proposed, in which the resolution of a node's map of the network is a function of distance. This enables the decrease of the overhead associated with the flooding of LSPs.
- *Border Discovery*: The Mobile Mesh Border Discovery Protocol (MMBDP) is a mechanism that is used to interconnect autonomous wireless ad-hoc networks that run the mobile mesh routing protocol, over a wired network. This is accomplished by setting up tunnels between the border routers across the wired network. The border discovery protocol enables a border router to discover other border routers and then set up tunnels with them. The Mobile Mesh is the preferred mesh networking protocol for the IpMesh software package [IpMesh].

3.2 Reactive Mesh Routing Protocols

3.2.1 Ad-hoc On-Demand Distance Vector (AODV)

Ad-hoc On Demand Distance Vector (AODV) [Perkins et al., (2003)] is a reactive routing protocol designed for ad-hoc networks. In AODV, each node maintains a routing table that is used to store the destination, next hop IP addresses and destination sequence numbers. Each entry in the routing table includes a destination address, next hop, precursor nodes list, lifetime, and distance to destination. To initiate a route discovery, a node broadcasts a route request packet, specifying the destination node. Each node forwards the route request packet and sets up a forward path entry to the destination in its routing table. To avoid the formation of loops, each route discovery packet contains a monotonically increasing broadband ID number that is incremented each time the source node initiates a route request. If the destination node receives a route request packet, it unicasts a route reply message back to the source. Route error messages are also used to notify other nodes of link breaks in existing routes. LocustWorld Mesh Networking [LocustWorld] uses AODV for its solutions: non-commercial - MeshAP and commercial- MeshAP-Pro.

3.2.2Dynamic Source Routing (DSR)

Dynamic Source Routing (DSR) is a reactive routing protocol proposed by [Johnson et al. (2001)]. It has two important phases: route discovery and route maintenance.

During the route discovery phase, a node broadcasts a route request packet, specifying the destination node. In DSR, each data packet has in its header a complete list of all intermediate nodes to the destination. Each intermediate node appends its address to the list of the packets and forwards the route request packet. If the destination receives the route request, it sends back a route reply packet containing a copy of the accumulated route along the reverse direction of the path over which the route request arrived.

Route Maintenance is used to detect if the network topology has changed. Each node along the route, when transmitting the packet to the next hop, is responsible for detecting whether its link to the next hop was broken. If a broken link is detected, the detecting node sends a route error message to the source node. Then, the source node can either use another route it knows or invoke route discovery again.

Although DSR can support relatively rapid rates of mobility, it is assumed that the mobility is not so high as to flood the only possible way for the exchange of packets between the nodes. Many variants of the DSR have been developed for commercial mesh solutions.

3.2.3 SrcRR

MIT Roofnet [MIT] uses a new routing protocol called SrcRR which is a variant of the DSR and its main goal is to find high-throughput routes. The primary difference between SrcRR and DSR is that SrcRR uses the Expected Transmission Count (ETX) metric to help it choose good routes. ETX continuously measures the loss rate in both directions between each node and its neighbors using periodic broadcasts. It assigns each link a metric that estimates the number of times a packet will have to be transmitted before it (and the corresponding 802.11 ACK) is successfully received; thus, the best link metric is unique. The ETX route metric is the sum of the link metrics; therefore, ETX penalizes both long routes and routes that include links with high forward or reverse loss rates.

3.2.4 Link Quality Source Routing (LQSR)

Microsoft uses a variant of the DSR as a routing protocol for its mesh solution [Microsoft Mesh Networks]. The protocol is called Link Quality Source Routing (LQSR) protocol. LQSR supports both single and multiple radios per node and a variety of link quality metrics including ETX, Per-hop Round Trip Time (RTT), Packet Pair and Hop Count. In addition, it also includes a new link quality metric called Weighted Cumulative Expected Transmission Time (WCETT). WCETT takes link bandwidth, link loss rate, and channel diversity into account when selecting links in a multi-radio mesh network.

For multi-radio nodes, a variant of LQSR called Multi-Radio LQSR (MR-LQSR) is proposed in [Draves et al. (2004)]. In MR-LQSR a new performance metric, called Weighted Cumulative Expected transmission time (WCETT) that takes into account both link quality metric and the minimum hop-count and achieves good tradeoff between delay and throughput, is incorporated.

3.2.5 Predictive Wireless Routing Protocol (PWRP)

The Tropos Company [Tropos Networks] has developed its own wireless routing protocol, called Predictive Wireless Routing Protocol (PWRP) that does not rely only on hop count to detect transmission paths, but compares packet error rates and other network conditions to determine the best path at a given moment. Based on a history of these measurements, PWRP dynamically tunes the selection of multi-hop paths from the available paths in the wireless mesh network. By estimating the throughput of each alternative path using advanced multi-hop metrics, PWRP ensures that it consistently selects paths amongst the best few available paths in order to obtain a stable and high throughput rate for wireless mesh clients.

3.3 Hybrid Mesh Routing Protocols

3.3.1 MeshNetworks Scalable Routing (MSR)

The MeshNetwork company has also developed a proprietary hybrid ad-hoc routing protocol that combines both proactive and reactive routing algorithms, called MeshNetworks Scalable Routing (MSR™). With this methodology, network topology dynamics, local RF conditions and degree of node mobility influence the routing metrics used on a moment-by-moment basis. The MSR is used for the Motorola’s multi-hop solutions.

4. Requirements for Wireless Health Mesh Networks and Application Scenarios

In wireless health networks, in contradiction to the general-purpose networks; efficiency is not the primary criterion for the selection of the routing protocol. There are several factors that influence the decision for the selection of the proposed algorithm and should be taken into account:

- Availability: In health networks the availability of resources is absolutely imperative, since the generated traffic maybe crucial for the patients’ health and life.
- Reliability: In health networks, more emphasis to the delivery of data is needed. In an emergency care, packet losses during the transmission of

medical information have disastrous impacts to a patient’s diagnosis. Therefore, fast reconfiguration and support of multiple gateways is essential.

- Confidentiality and Privacy: The delivery of the sensitive patients’ data demands several degrees of security. Therefore, several authentication mechanisms are needed in order to ensure the confidentiality and privacy of the patients’ data. However, these mechanisms are out of the scope of this paper.
- Data delivery latency: The quick delivery of a patient’s measurements is an extremely important issue, especially in emergency situations.
- QoS Support: The requirement for significant Quality of Service (QoS) is essential in health communication systems.

The selection of the routing algorithm not only depends on the factors that influence decision/selection, but it also depends on the application scenario the wireless mesh networks are used. We distinguish three categories of scenarios:

- In home-health care: This category involves situations where a connection of home or point-of-care devices to a central management system or to a remote physician is installed. Applications of this category include monitoring of patients with chronic conditions or children with intermediate intensity health care needs. The use of WMNs for home health care applications requires reliable delivery of monitoring messages. The size of the delivered information is small and the delivery of information is usually performed on a regular basis.
- Emergency response: This category refers to emergency response situations, such as patient’s transport to a hospital, or delivery of immediate notifications on changes in patient status, such as respiratory failure or cardiac arrest. In the emergency response applications, the immediate delivery of data is a critical issue. Therefore, the delay and the jitter of data transmission should be minimized.
- Teleconsultation: This category involves situations of real-time consultation between referring physicians and experts. In these applications, the degree of interactivity determines the level or stringency of the delay requirement.

5. Routing Protocols Selection in Wireless Mesh Health Networks

Proactive algorithms are usually suitable for small in size networks with low mobility, since in this situation the routing overhead, in maintaining the routes and the memory requirement to store the routing table, is low. Therefore, proactive algorithms are preferable for home health care application scenarios in which the small number of users and their low mobility permit the efficient usage of the proactive algorithms.

The OLSR protocol ensures the availability of resources, through its multipoint relay (MPR) concept. Therefore, it performs well in small and low mobility networks where the delivery of information is performed on a regular scheduled basis. However, since TBRPF generates less control traffic protocol, it consumes less energy and is more preferable when continuous monitoring is needed. On the other hand, in cases where different networks are connected through the mesh routers e.g. Internet connectivity, the MobileMesh should be used, since in these situations explicit tunneling is needed in order to route the packets consistently over a specific gateway.

Reactive algorithms are preferable in large networks with high mobility, since the need to store routes towards all the destinations would impose considerable memory requirement and cause lookup delays. Therefore, reactive algorithms are also preferred for emergency and teleconsultation applications. More specifically, DSR is suitable for emergency response applications, since it can support relatively rapid rates of mobility and its routing metric can be easily and fast computed. On the other hand, LQSR, PWRP and SrcRR are more preferable for teleconsultation applications since the routing metrics that are used provide guaranteed QoS. However, if there are fluctuations in traffic, these routing metrics may cause instability, long delay and ineffective service for emergency traffic. The less routing metrics are used, the less delay is minimized.

MSR may be considered the most applicable solution for health scenarios, since its hybrid nature, make it suitable for the most health application scenarios.

Table 2 summarizes health application scenarios and the suitable routing protocol.

Table 2. *Application Scenarios and Routing Protocols*

Scenarios	Use	Routing Protocols
In home-health care	Periodical RF-Monitoring Continuous RF-Monitoring Monitoring Wireless System	OLSR TBRPF MobileMesh
Emergency Response	Health Constellations	DSR
Teleconsulation	Telediagnosis	LQSR, PWRP and SrcRR

6. Conclusions

Wireless Mesh technology is a promising solution for wireless health environments. However, the performance of a wireless health mesh network depends on the routing protocol that is used. The selection of the routing algorithm depends on the influence degree of availability, reliability, confidentiality, privacy, and latency and the application category that each scenario belongs.

In a vast medical facility, where numerous wireless patients and caregivers are roaming and numerous concurrent connections are served at the same time, the proactive routing mesh protocols may prove to be inefficient. On the contrary, the optimized reactive protocols that take into consideration the variance in packet loss and available throughput, like SrcRR, PWRP and LQSR, are more suitable in these situations. Hybrid protocols, such as MSR, seem to be the most applicable solutions for wireless mesh health systems.

7. References

Akyildiz I. F. and Wang X. (2005), “ A survey on wireless mesh networks”, *IEEE Communications Magazine*, no. 43, vol. 9, pp.23–30.

Clausen T. and Jacquet P. (2003), “Optimized link state routing protocol (OLSR)," *RFC 3626*, Internet Engineering Task Force IETF, October. 2003, Available at: http://www.ietf.org/internet-drafts/draft-ietf-manet-dsr-10.txt

Draves R., Padhye J., and Zill B. (2004), “Routing in multi-radio, multi-hop wireless mesh networks”, *In the Proceedings of Mobicom* ’04.

Firetide, Inc. Available at: http://www.firetide.com.

IpMesh software package. Available at: http://ipmesh.sourceforge.net .

Johnson D. B., Maltz D. A., and Broch J. (2001), “DSR: The dynamic source routing protocol for multihop wireless ad hoc networks", *Ad Hoc Networking*, Addison-Wesley, 2001, ch. 5, pp. 139-172.

Kowalik K. and Davis M. (2006) , “Why Are There So Many Routing Protocols for Wireless Mesh Networks?”, *In the Proceedings of the Irish Signal and Systems Confrerence(ISSC ’06* ,Dublin , Ireland

Lee M. J., Zheng J., Ko Y.-B., and Shrestha D. M. (2006), “ Emerging Standards for Wireless Communications”, *IEEE Wireless Communications*, pp. 56-63.

LocustWorld Mesh Networking. Available at: http://www.locustworld.com

Meshnetworks. Available at: http://www.meshnetworks.com

Microsoft Mesh Networks. Available at: http://research.microsoft.com/mesh .

MIT Roofnet. Available at: [http://pdos.csail.mit.edu/roofnet/doku.php]

Mitre Corporation. Available at: http://www.mitre.org.

Motorola Company: Available at: http://www.motorola.com

Ogier R., Templin F., and Lewis M. (2004), “Topology dissemination Based on Reverse-Path forwarding (TBRPF)”, *RFC 3684, Internet Engineering Task Force IETF*, February 2004. Available at: http://www.ietf.org/rfc/rfc3684.txt

Perkins C., Belding-Royer E., and Das S. (2003), “Ad hoc Vector (AODV) Routing”, RFC 3561, July 2003. Available at: http://www.ietf.org/rfc/rfc3561.txt

The SeattleWireless project. Available at: http://www.seattlewireless.net/SeattleWireless

Tropos Networks. Available at: http://www.tropos.com/technology.