Review

A Comprehensive Survey on Opportunistic Routing Protocols for MANETs: Issues, Challenges and Future Directions

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Abstract: Opportunistic routing is the latest technique that uses the broadcasting nature of the wireless medium to increase the number of potential forwarding nodes in the network. This, in turn improves the delivery rate and reliability of data transmission in the network. Compared to all previous classes of routing protocols, opportunistic routing offers numerous advantages which is exploited by the latest applications for efficient communication and resource sharing in dynamic ad hoc networks. These applications provide dynamic communication in disaster recovery environments. The objective of this research work is to review and classify all the major opportunistic routing protocols proposed for dynamic ad hoc networks. Further the issues and challenges with each of these existing protocol is discussed and future research directions are put forward

Keywords: Ad Hoc Networks; Classification; Dynamic; Mobility; Opportunistic Routing; Performance Improvement; Review; Survey

1. Introduction

Flexibility and rapid adaptability to infrastructure-less locations have led to the growing popularity and deployment of Mobile Ad hoc Networks (MANETs) [1-10] for communication purposes. Today, MANETs are being used for communication, disaster recovery operations and resource sharing. Working as an autonomous system, all the devices in MANETs can dynamically join or leave the network at any time without disrupting the communication. Every device in the network plays the dual role of a router and a host, cooperates and coordinates with each other to make routing decisions in the network. Data is transmitted in the network in a store and forward manner from the source node to the destination node via the intermediate nodes. Ease of deployment, speed of deployment and the ability to self-organize and self-adapt is some of the major advantages of this network.

One of the major challenge in MANETs is in efficiently routing the data packets from the source to the destination. Traditional topology based protocols like Destination Sequenced Distance Vector (DSDV) [11], Optimized Link State Routing (OLSR) [12], Topology Dissemination Based on Reverse-Path Forwarding (TBRPF) [13], Dynamic Source Routing (DSR) [14], Associativity-Based Routing [15], Ad hoc On Demand Distance Vector (AODV) [16] and Temporally Ordered Routing Algorithm (TORA) [17] depend on predetermined routes between source and destination devices. With highly mobile nodes, it is impossible to maintain a deterministic route. Also the discovery and recovery procedures are time and energy consuming. The new class of protocols known as geographic routing protocols [18-22] used location information to route the packets in a hop by hop fashion from the source device to the destination device. Most of these protocols selects the device that has maximum progress to the destination (nearest to the destination) as the best forwarder to forward the data

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packet. These protocols suffer from many limitations in dynamic ad hoc networks especially when the best forwarder is unavailable.

Opportunistic routing and forwarding have provided an efficient solution to this problem. Opportunistic routing protocols [23-44] were proposed to offer reliable data delivery and excellent Quality of Service (QoS) to applications using MANETs for communication and resource sharing. Numerous advantages offered by OR protocols have enabled researchers to use them for communication in MANETs deployed in some of the harshest environments like volcanoes, hurricane affected regions and underground mines. They are currently being used in a wide range of applications spanning from communication between rescue workers in disaster recovery operations battlefield communications, industrial sites interconnection, emergency evacuation and recovery, setting up communication in conferences and exhibitions to providing internet connections in rural areas.

The major contributions of this paper are,

- Comprehensive review of all major opportunistic routing protocols proposed for dynamic ad hoc networks. The advantages of each of the protocol is discussed and the issues and limitations of each of the protocol is highlighted.
- Taxonomy of all the protocols is developed according to their working parameters. The working and behavior of each class of protocol is explained in detail.
- Issues and challenges existing in the current opportunistic routing protocols are discussed and the future research directions are proposed.

Next section discusses the background and preliminaries behind opportunistic routing.

2. Background

Mobile Ad Hoc Networks

Mobile ad hoc networks (MANETs) are a collection of wireless devices like mobile phones, laptops, PC's and iPads that can form instantaneous temporary networks without the support of any pre-existing network infrastructure or centralized control. It works as an autonomous system of mobile hosts connected by wireless communication links. The network is configured in a way that all the devices can dynamically join or quit the network at any time without disrupting communication between other devices. Every device in the network plays the dual role of a router and a host, cooperates and coordinates with each other to make routing decisions in the network. Data is transmitted in the network in a store and forward manner from the source node to the destination node via the intermediate nodes.

Ease of deployment, speed of deployment and the ability to self-organize and self-adapt without the help of any underlying infrastructure has contributed to the growing popularity of MANETs in research as well as in industry. Today MANETs are used for communication and resource sharing in a wide range of applications. Figure 1.1 illustrates an example of a simple MANET.

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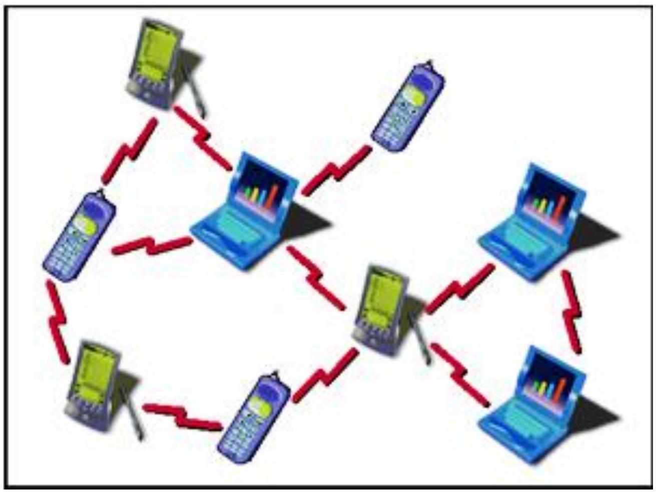

Figure 1 Mobile Ad Hoc Network

Challenges in MANETs

MANETs are autonomous systems that can be set up dynamically at any place using a group of wireless devices like mobile phones, laptops, iPads etc. and without the help of any infrastructure like base stations or access points. The network does not have any centralized authority for control and management. Devices are free to join or quit the network at any point of time. At every time, all the devices are free to travel throughout the network in any direction and with any random speed.

Routing of data packets from the source to the destination device is managed with dual role of a host and router played by all the devices in the network. Every device can communicate directly with the other devices residing in its transmission range. To communicate with devices that are outside the transmission range, each device has to use the intermediate devices as relay devices and transmit the data packet hop by hop. MANETs derive a number of challenges associated with the wireless communication channel. They are,

- Lack of protection from outside signals.
- Lack of fixed boundaries.
- Time varying and asymmetric propagation properties of the channel.
- Interference and error prone wireless channel.

The major characteristics, issues, concerns and challenges of MANETs are,

- Infrastructure less and autonomous system.
- Variation in link and device capabilities.
- Constraints in energy.
- Network scalability.
- Routing with dynamic network topology.

Static and Dynamic MANETs

MANETs are classified into static and dynamic based on the movement and speed of wireless devices in the network. Static MANETs have devices with zero or very less mobility. The wireless devices in the network do not move much in static MANETs. Many industrial and healthcare applications use static MANETs for communication and continuous monitoring.

Dynamic MANETs have mobile devices that change their position continuously in the network. Majority of the latest applications used for communication and resource sharing are working with dynamic MANETs. Recently the speeds of the mobile devices are increasing rapidly and their movement in the network have become highly unpredictable. This has led to the generation of Highly Dynamic Mobile Ad hoc Networks (HDMANETs). This research focuses on the working of HDMANETs. Next section discusses the characteristics and working of HDMANETs.

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Highly Dynamic MANETS

Recent advancements in wireless technology have enabled mobile devices to move freely with higher speeds in random directions in ad hoc networks. The mobility and speed of these wireless devices have become highly unpredictable and is increasing day by day. Also the number of connected devices in the network is increasing rapidly leading to highly dense and scalable ad hoc networks. These scenarios have led to the generation of highly dynamic mobile ad hoc networks (HDMANETs) in which numerous number of connected wireless devices move with higher speeds in random directions.

HDMANETs offer a number of challenges to various applications due to its unique properties. The main characteristics of HDMANETs are,

- Continuous movement of wireless devices.
- Higher speeds of wireless devices.
- Unpredictable movement of devices in random directions.
- Higher number of connected devices.
- Dynamic connections, disconnections and reconnections of devices.

Routing in HDMANETs

This research focuses on the challenge of routing of data packets from the source to the destination in HDMANETs. The unpredictable and frequent change in device position is the major challenge involved in routing inside HDMANETs. Dynamic network topology caused by random device movements leads to frequent link failures and data loss.

This often leads to increased number of data retransmissions for the successful delivery of data packet from one hop to the other in HDMANETs. Energy constrained wireless devices is another major issue in designing a routing strategy for HDMANETs. Complexity of the routing technique and the routing overhead incurred is another major challenge in routing. Error prone wireless channel and interference are other major challenges involved in routing of data packets in these networks. Next section discusses various routing protocols that have been proposed for MANETs. Most of these protocols do not perform well in HDMANETs.

Routing Protocols

This section gives a brief introduction to the various existing routing protocols proposed for MANETs and HDMANETs. Figure 2 depicts the broad classification of various types of routing protocols proposed for MANETs and HDMANETs over these years.

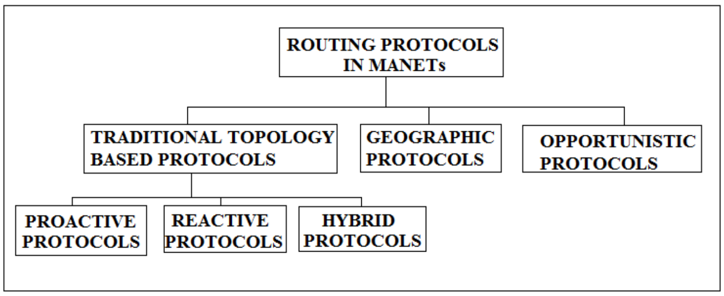

Figure 2 Categories of Routing Protocols in MANETs

The entire routing protocols proposed for MANETs can be divided into three major categories,

- Traditional Topology Based Routing Protocols
- Geographic Routing Protocols
- Opportunistic Routing Protocols

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Traditional topology based routing protocols were the earliest proposed protocols that depended on predetermined routes from the source to the destination device. Most of these protocols had a number of limitations in working in MANETs. These protocols are classified into three categories,

- Table Driven Proactive Routing Protocols
- Reactive On Demand Routing Protocols
- Hybrid Routing Protocols

Table driven proactive routing protocols try to maintain updated route information from every device to the other devices in the network. The methodologies used by this type of protocols are similar to the conventional distance vector and link state routing strategies. This type of protocols periodically sends routing table updates in the network. Every device acknowledges the topology changes in the network by propagating route updates throughout the network to maintain a consistent network view.

Destination Sequenced Distance Vector (DSDV) Optimized Link State Routing (OLSR) and Topology Dissemination Based on Reverse-Path Forwarding (TBRPF) are the major protocols proposed in this category. Most of these protocols often depend on stable topologies and predetermined routes in the network for efficient routing of data packets from source to the destination device. Due to movement of devices in the network, it is often impossible to maintain predetermined and accurate route information in MANETs. These protocols therefore do not perform well with MANETs and suffer from significant performance degradation. The performance of these protocols comes down further with increasing mobility of devices, making them highly unsuitable for HDMANETs.

Reactive on demand routing protocols creates routes only when they are requested by the source device. A device initiates the route discovery process once it wants to send a data packet to a destination device. Once a route is established, it is maintained until the destination become unreachable. Dynamic Source Routing (DSR) Associativity-Based Routing, Ad hoc On Demand Distance Vector (AODV) and Temporally Ordered Routing Algorithm (TORA) are the major protocols in this category. Due to unpredictable and frequent movement of devices, source initiated routes become obsolete frequently and this leads to their poor performance in MANETs. Further the performances of these protocols come down drastically with higher mobility of devices and are unsuitable for HDMANETs.

To overcome these problems, a new class of routing protocols was proposed based on the location information of the devices in the network. This new class of protocols known as geographic routing protocols used location information to route the packets in a hop by hop fashion from the source device to the destination device. Greedy Perimeter Stateless Routing (GPSR) is the most referenced protocol in this category. This protocol selects the device that has maximum progress to the destination (nearest to the destination) as the best forwarder to forward the data packet. When this strategy was not possible in some region in the network, GPSR used a technique of routing around the perimeter of the region. But the major problem with this category of protocols in HDMANETs was when the best forwarder device moved away from the current location and it became impossible to forward the data packet.

A major breakthrough in this area was provided with the discovery of opportunistic routing and opportunistic data forwarding. Opportunistic routing protocols) were proposed to offer reliable data delivery and good Quality of Service for applications using HDMANETs for communication and resource sharing. Next section gives a brief summary of the working of opportunistic routing protocols.

3. Opportunistic Routing

The concept of opportunistic routing was first given by Extremely Opportunistic Routing (ExOR) [44] protocol This was the first protocol aimed at exploiting and taking advantage of the broadcasting nature of the wireless channel to improve performance of data delivery in the network. Opportunistic Routing (OR) utilized the reception of the same broadcasted packet at multiple devices

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in the network and selected one best forwarder device dynamically from the set of multiple receivers. The most important advantage of this class of protocols is that they do not commit to a fixed route before data transmission. The next forwarder device and the route are only determined dynamically based on current network conditions and thus leads to its better performance compared to all previous classes of routing protocol proposed for dynamic ad hoc networks.

When a sender device wants to send a data packet to a particular destination device, it broadcasts the data packet to a list of candidate devices that are in its transmission range. Now these candidate relay devices are prioritized based on some metric like Expected Transmission Count (ETX) or Expected Transmission Time (ETT) calculated dynamically from the network. The candidate devices that receive the data packet run a coordination scheme to determine the best forwarder for the current data packet. Thus the forwarder device is selected dynamically from the network based on current network characteristics. The data packet is then forwarded by the best forwarder device and this opportunistic routing strategy continues till the data packet reaches the destination.

Stages in Opportunistic Routing

The complete working of OR can be divided into four stages. Every stage has equal importance in achieving good performance with OR in dynamic networks. The four stages are,

Selection of Candidate Set

Initially in the first phase of selection of candidate set, the sender device generates a list of candidate devices from the neighbouring devices that are in its transmission range. The source device may use periodic or non-periodic message broadcasts to discover and maintain the list of candidate devices in the network.

Data Broadcast

Once the candidate set is selected, the data packet is broadcasted by the sender to all the devices in the candidate set. This is the major advantage of having multiple forwarders with opportunistic routing, as more than one candidate device receives the data packet and is ready to forward the data packet.

Prioritization of The Forwarder Devices

In the next phase, OR would sort the devices in the candidate sets based on a particular metric calculated dynamically from the network. A number of metrics like Expected Transmission Count (ETX) [34] Expected Any Path Transmission (EAX), Expected Transmission Time (ETT) Expected Any Path Transmission Time (EATT) Expected Duty Cycle (EDC) etc. are used for prioritization of forwarder devices. Based on the metric, the best forwarder device was selected to forward the data packet to the destination.

Data Forwarding by the Selected Forwarder Device

Once the priority of devices was generated using the specific metric calculated from the network, the data packet is forwarded by the best forwarder device in the list. This strategy is used by OR till the packet reaches the destination device.

Advantages of Opportunistic Routing

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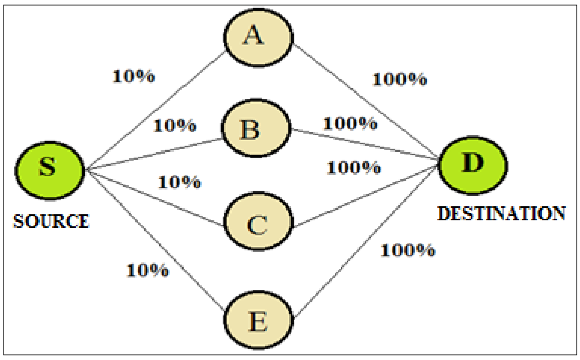

Figure 1 Advantage of Opportunistic Routing (illustration)

Figure 1 depicts the advantage of Opportunistic Routing (OR) over conventional routing schemes. Here the MANET consists of a source device S and a destination device D with intermediate devices A, B, C and E. The end to end delivery probabilities over each transmission link in the network is assumed as shown in the figure.

Using OR concept the end to end delivery probability for data transmission in the network from source device S to destination device D is obtained as $P_{OR} = (1- (1-0.1)^4) \times (1) \approx 0.3$ which is the probability that at least one device among the four candidate devices (A, B, C, E) forwards the data packet to the destination.

Using conventional routing strategy, the end to end delivery probability of data transmission is obtained as, $P_{Conventional} = (0.1) \times (1) = 0.1$. This value is much less compared to the Opportunistic Routing strategy. This proves the fact that OR protocols work much better compared to traditional routing strategies.

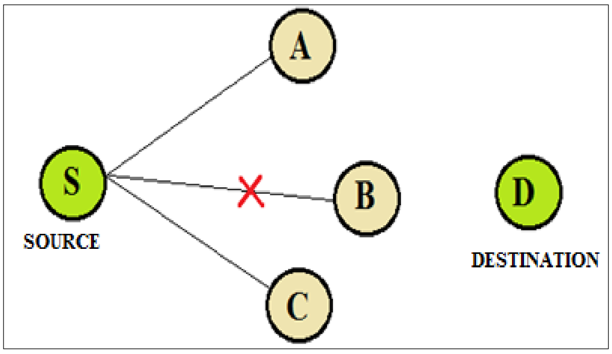

Figure 2 Increased Reliability with Opportunistic Routing

Figure 2 depicts the increased reliability in data transmission with OR strategy. Here device S wants to transmit a data packet to device D in the mobile ad hoc network. An assumption is made that the transmission link from S to B is having the highest delivery probability and thus using OR strategy device B is selected as the next forwarder device in the network. Using OR strategy the data packet broadcasted by source device S is received by all three intermediate devices A, B, C. So if device B is unable to forward the data packet, device A or device C will forward the data packet. Thus OR is more reliable compared to all the other categories of routing protocols.

Figure 3 illustrates the improvement in transmission range offered by OR. Here the device S has three intermediate devices (candidate devices, A, B and C) to forward data to the destination. Using OR strategy, device S may select device B as the best forwarder based on certain metric calculated from the network. But the data packet sent by the source device may be received by device A also. So device A which is much closer to the destination would forward the data packet, thus reducing the

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number of transmissions and improving the transmission range of devices in the network using opportunistic routing.

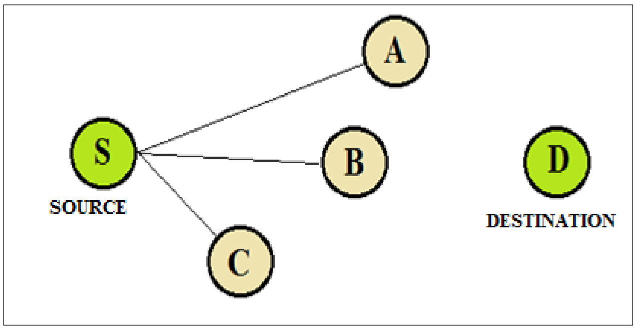

Figure 3 Improved Transmission Range with Opportunistic Routing

Applications of Opportunistic Routing

Opportunistic Routing has become very popular due to numerous advantages offered by them in communication and resource sharing applications in dynamic ad hoc networks. Today OR is used by a number of important and sensitive applications. Some of the major applications of OR are,

- Communication between the rescue officers in disaster recovery operations.
- Communication in earthquake and volcano affected areas.
- Providing internet for rural areas that are remote and difficult to be reached.
- Communication in underground mines.
- Communication and resource sharing in underwater sensor networks.
- Communication in oil and gas industry.
- Communication in emergency situations.
- Communication in battlefields.

3. Taxonomy of Opportunistic Routing Protocols

In this research a standard taxonomy of entire OR protocols are devised based on their working. Figure 4 depicts the classification of OR protocols based on their working.

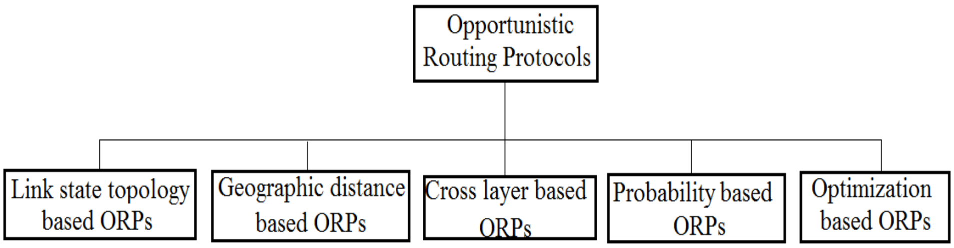

Figure 4 Classification of OR Protocols Based on their Working

Link State Topology Based Opportunistic Routing Protocols uses link delivery probabilities for candidate list generation and in making decisions on best forwarder device in the network. Geographic Distance Based uses the information on the distance between the devices in the network to make routing decisions. Cross Layer Based Opportunistic Routing Protocols make use of information from MAC and Physical layers in making routing decisions in the network. Probability Based Opportunistic Routing Protocols use delivery probabilities in the network for making routing decisions and Optimization Based Opportunistic Routing Protocols tries to optimize the candidate set using machine learning approach, graph theory etc. Table 1 presents the Taxonomy of entire OR protocols proposed for dynamic MANETs.

Table 1. Taxonomy of Opportunistic Routing Protocols

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Link State Topology Based ORPs	Geographic Distance Based ORPs	Probability Based ORPs	Cross Layer Based ORPs	Optimization Based ORPs
ExOR (Biswas and Morris, 2005)	ROMER (Yuan et al., 2005)	FPOR (Conan and Friedman, 2008)	PRO (Lu et al., 2009)	LCOR (Dubois-Ferriere et al., 2007)
OAPF (Zhong et al., 2006)	OPRAH (Westphal, 2006)	Delegation Forwarding (Erramilli et al., 2008)	ILOR (Bletsas et al., 2010)	OMNC (Zhang and Li, 2009)
MORE (Chachulski et al., 2007)	DTRP (Nassr et al., 2007)	OR-Flooding (Guo et al., 2009)	SPOR (Lee and Haas, 2011)	Consort (Fang et al., 2011)
Code OR (Lin et al., 2008)	GOR (Keng et al., 2007)	OPF (Lu and Wu, 2009)	EEOR (Mao et al., 2011)	AdaptOR (Bhorkar et al., 2012)
XCOR (Koutsonikolas et al., 2008)	DICE (Zhang and Li, 2008)	EBR (Nelson et al., 2009)	CORMAN (Wang et al., 2012)	PLASMA (Laufer et al., 2012)
Economy (Hsu et al., 2009)	POR (Yang et al., 2009)	MaxOpp (Bruno and Conti, 2010)	QOR (Lampin et al., 2012)	TOUR (Xiao et al., 2013)
SOAR (Rozner et al., 2009)	MGOR (Zeng et al., 2009)		Parallel-OR (Shin and Lee, 2013)	ORL (Tehrani et al., 2013)
Slide OR (Lin et al., 2010)	TLG-OR (Zhao at al., 2013)		MTOP (Lee et al., 2013)	MAP (Fang et al., 2013)
O3 (Han et al., 2011)	XLinGo (Rosario, et al., 2014)		CAOR (Zhao et al., 2014)	LOR (Li et al., 2013)
			ORW (Ghadimi et al., 2014)	

4. LINK STATE TOPOLOGY BASED ORPs

Link state topology based opportunistic routing protocols make use of a link state style updating mechanism for the calculated metric in the network. Also they use link delivery probabilities as the decision making metric in the network. Further they try to notify each device with the delivery probability of every link in the network using the link state type topology and updating mechanism.

The first OR protocol proposed in this category was Extremely Opportunistic Routing (ExOR) protocol [44]. This protocol introduced the batching systems in which a group of 10 to 100 packets were broadcasted by the source device. This broadcasted group of data packets also consisted of information on the potential forwarder devices. The priority of the devices was decided using the Expected Transmission Count (ETX) metric which calculated the expected number of transmissions for successful delivery of a packet over a link in the network. The major disadvantage of ExOR is that it uses a link state topology updating scheme. ExOR requires periodic network wide measurement of ETX value which is very difficult in Dynamic MANETs with extremely mobile devices. Moreover, communication and coordination between the candidate devices generated duplicate transmissions when they were connected with links of low quality. Further, ExOR protocol gave low QoS in Dynamic MANETs and its performance degraded with increasing mobility of devices in the network.

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Opportunistic Any Path Forwarding (OAPF) protocol [45] improved on ExOR protocol with a new metric known as Expected Any Path Transmissions (EAX) which calculated the expected number of transmissions for successful delivery of data packet between a pair of devices in the network. This metric was used by OAPF for candidate list generation and prioritization of the forwarder device. This protocol also required network wide periodic measurement of EAX and continuous updating which was quite impossible in extremely mobile environments. Thus this protocol too suffered from performance degradations in Dynamic MANETs.

MAC-Independent Opportunistic Routing and Encoding (MORE) protocol [46] tried to increase the throughput of the network by integrating network coding into OR. This protocol too used the batch mechanism in its operation and obtained better performance than ExOR protocol in. MORE was one of the first protocols to use network coding as the coordination method between the candidate devices in the network. This protocol used ETX as the metric to generate the candidate set and to prioritize the potential forwarder devices. Although MORE achieved higher performance than previous ORPs, this protocol too suffered from a major problem of increased duplicate transmissions in the network and had issues with batch sizes and limits.

Code OR protocol [47] is another link state OR protocol that combined OR with segmented network coding. This protocol too used ETX for candidate list generation and prioritization. Although this protocol offered better throughout, it suffered from many problems in Dynamic MANETs. It was quite difficult to determine the optimal segment size of the data packet with this protocol and this contributed to the increased overhead in data transmission in the network.

XCOR [48] protocol also used similar OR and network coding strategies like Code OR and MORE protocols. The major difference is that; this protocol was depended on neighbor overhearing for coordination between the devices. Neighbor overhearing method was introduced to reduce the overhead incurred by OR in Dynamic MANETs with extremely mobile devices. XCOR prioritized the devices in candidate set based on ETX value calculated from the network. One of the unique features of XCOR protocol was that every device in the candidate set sends a report of received packets to every other device in the set. This helped to reduce the duplicate transmission among the devices in the network. Although XCOR reduced some duplicate data transmissions in the network, it could not offer betterQoS and high performance in Dynamic MANETs.

Economy protocol [49] was proposed to reduce the duplicate transmission in extremely mobile networks caused by previous OR protocols. Economy protocol introduced a new concept which removed numerous unused and unreachable devices from the candidate list and reduced duplicate transmissions. Token passing method was used by this protocol for coordination between the forwarder devices in transmitting a data packet in the network. Economy gave better throughput in the network compared to previous OR routing strategies, but incurred high overhead in data transmission and it remained unsuitable for extremely dynamic MANETs.

Simple Opportunistic Adaptive Routing (SOAR) protocol [50] was an improved version of ExOR protocol and it used the same batching mechanism to transmit the data packets in the network. Design and working of this protocol was uncomplicated and new techniques could be easily integrated to the protocol. Although it offered better performance compared to ExOR and other OR protocols, SOAR also suffered from the problem of periodic updating of the ETX metric in Dynamic MANETs.

Cumulative Coded Acknowledgments (CCAK) [51] and Slide OR [52] used similar network coding strategies with OR in dynamic MANETs. Slide OR used a segmented coding mechanism and combined the packets belonging to different overlapping segments to increase the throughput of data transmission in the network. Both the protocols tried to improve the reliability of data transmission in the network and achieved higher throughput compared to previous OR protocols in dynamic MANETs. But both these protocols suffered from performance degradations with increase in mobility of devices in Dynamic MANETs.

Optimized Overlay-based Opportunistic routing (O3) [53] was one of the advanced OR protocols using network coding proposed in this category. The main objective of this protocol was to introduce a standard in the number of optimal coded packets that needs to be transmitted at a time in the network. This protocol solved some of the issues that existed in OR protocols with network coding. Although this protocol offered better throughout compared to the previous OR protocols, this protocol too suffered from performance degradations with increased mobility of devices in Dynamic MANETs.

Table 2 summarizes the issues and drawbacks faced by link state based OR protocols in Dynamic MANETs. Most of these protocols suffered from limitations in periodic network wide measurement of different metrics in the network used for candidate set generation and prioritization. Also they suffered from increased redundant data transmission with rising mobility of devices in the network. Due to these limitations, applications have moved from link state OR protocols to optimized, probabilistic, cross layer based and geographic OR protocols for communication and resource sharing in Dynamic MANETs with extremely dynamic devices.

Table 2. Issues and Challenges with Link State Based OR Protocols in Dynamic MANETs

Protocol	Metric	Coordination Method	Issues and Drawbacks
ExOR	ETX	Timer + ACK	Limitations in periodic measurement of ETX metric due to link style topology. Duplicate transmissions with low quality links.
OAPF	EAX	ACK	Limitations in periodic measurement of EAX metric due to link style topology. Low QoS in .
MORE	ETX	Timer	Redundant packet transmissions. Issue with batch size and limits.
Code OR	ETX	ACK	Determining the optimal segment size. Managing the sliding window size. Higher overhead.
XCOR	ETX	Timer + Overhearing	Low QoS in dynamic ad hoc networks. Duplicate data transmissions.
Economy	ETX	Timer	Limitations in network wide ETX measurement. High overhead.
SOAR	ETX	Timer	Usage of link state style topology database. Limitations in periodic network wide measurements.
CCAK	ETX	ACK	Limitations in network wide ETX measurement. High overhead. Duplicate data transmissions.
Slide OR	ETX	ACK	Limitations in network wide ETX measurement. High overhead. Duplicate data transmissions.
O3	ETX	Timer	Limitations in network wide ETX measurement. High overhead. Duplicate data transmissions.

5. Geographic Distance Based ORPs

Geographic opportunistic routing strategies used the location information of the devices to generate the candidate list and to prioritize the set of forwarder devices. This type of OR protocols were much more flexible and dynamic compared to other categories of OR protocols and offered better performance.

Resilient Opportunistic Mesh Routing (ROMER) [54] was one of the first proposed geographic OR protocols. This protocol used location information of the devices in the network with probabilities in data transmission to prioritize the forwarder devices in the network. Using ROMER protocol, forwarder devices located in the shortest paths were assigned a probability of one in data transmission. This protocol helped to reduce the occurrences of packet dropping attacks in the network with extremely mobile devices. One of the major drawbacks with this protocol was the increasing number of duplicate transmissions with rising mobility of devices in the network. This protocol was therefore seldom used in Dynamic MANETs.

OPRAH protocol [55] used a number of positive techniques from the earlier proposed AODV routing protocol. The main feature of this protocol was in maintaining more than one route to the destination device in the network. Route with minimum number of hops was selected as the best route to the destination device. The major advantage of this protocol was that it was less complex and had low overhead. The major drawback of OPRAH protocol was that it suffered from duplicate data packet transmissions in the network. Moreover, often this protocol was unable to discover the optimal path to the destination, resulting in higher timing overhead and low performance in Dynamic MANETs.

Directed Transmission Routing Protocol (DTRP) [56] is another geographic OR protocol that used the transmission probabilities similar to ROMER protocol in dynamic ad hoc networks. Similar to ROMER, all the forwarder devices in the shortest path of transmission was assigned a probability one. All the remaining devices that took part in data transmission were assigned a different probability value calculated based on the current network scenario. Although this protocol gave higher delivery rate compared to previous OR protocols, it was mainly targeted for wireless sensor networks. The protocol used beacon messages for transfer of location information between the devices in the network. The major drawbacks of this protocol were high energy consumption and overhead in data transmission.

Geographic Opportunistic Routing (GOR) [57], was one of the earliest protocols to use the timer based coordination scheme among the various forwarder devices in the candidate set. Timer based coordination technique was much simpler and efficient compared to many previous methods used in Dynamic MANETs. This protocol used the Expected One Hop Throughput (EOT) metric that used the delay caused by the coordination process among the devices to make routing decisions in the network. GOR used the neighbor overhearing method to avoid packet retransmissions by lower priority forwarders in Dynamic MANETs with extremely mobile devices. Although the timer based coordination methods was better compared to the previous methods, GOR suffered from duplicate data transmissions in Dynamic MANETs.

Position Based Opportunistic Routing (POR) [58] and Multi-rate Geographic Opportunistic Routing (MGOR) [59] protocols used the information on the position of the devices in the network to generate the candidate set and also to prioritize the devices in the candidate set. MGOR protocol was an improved version of the GOR protocol and used the OEOT metric for candidate set generation and prioritization. Both the protocols achieved better performance compared to all previous protocols in Dynamic MANETs. Both protocols achieved higher throughput and lower delay compared to the previous protocols in Dynamic MANETs. The major issue with POR protocol was buffer occupancy in the devices. MGOR suffered from duplicate data transmissions in Dynamic MANETs.

TLG-OR [60] combined geographic location information with details of link quality between the devices and the remaining energy information of devices to improve the QoS for video traffic in Dynamic MANETs. Link quality and energy of the devices were the two most important parameters used by this protocol in deciding the forwarder devices in the network. This protocol however had higher overhead in data transmission and did not have any provision to handle communication voids in DYNAMIC MANETS with extremely dynamic devices. Also the protocol had serious performance degradations in wireless networks with interference.

XLinGo [61] protocol was also aimed to improve the quality of video transmission in Dynamic MANETs. This protocol also aimed at reducing the energy usage by the devices in routing of data packets in the network. This protocol offered better performance in video transmission compared to TLG-OR protocol in Dynamic MANETs. This protocol too had higher overhead in data transmission and did not have any provision to handle communication voids in DYNAMIC MANETS. Also this protocol was not suitable for use in Dynamic MANETs with extremely dynamic devices.

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Table 3 summarizes the issues and drawbacks faced by geographic distance based OR protocols in dynamic MANETs. Most of these protocols suffered from duplicate data transmission in the network and incurred high time overhead with increased mobility in the network.

Also most of them had no strategies to handle communication holes in the network. Some of the protocols had imitations in reliable delivery and continuous transmission of data in the network. Researchers tried to overcome these limitations using various probabilities as metrics along with location information in the network. Next section discusses the various probability based OR protocols proposed for Dynamic MANETs with extremely dynamic devices.

Table 3 Issues and Challenges with Geographic Distance Based OR Protocols in Dynamic MANETs

Protocol	Metric	Coordination Method	Issues and Drawbacks
ROMER	Hop count	Overhearing	Duplicate data transmissions with increasing mobility of devices
OPRAH	Hop count	Overhearing	Suffers from duplicate data packet transmission in the network. Often, unable to discover the optimal path to the destination Higher timing overhead
DTRP	Hop count	Timer	High energy consumption High time overhead No provision to handle communication voids
GOR	EOT	Timer + Overhearing	Redundant data transmissions No provision to handle communication voids
POR	Distance	Timer	Duplicate packet transmissions Increased buffer occupancy.
MGOR	OEOT	ACK + Overhearing	Time Overhead Redundant data transmissions
TLG-OR	Energy, Distance	Timer + Overhearing	Time Overhead Duplicate data transmissions with increasing mobility of devices
XLinGo	DFD+SSIM	Timer	Time Overhead Redundant data transmissions

6. Probability Based ORPs

Probability based OR protocols used various probabilities of data transmission and delivery in the network as the main metric in candidate set calculation. A number of OR protocols depending on probability of data delivery, links and transmissions have been proposed over these years.

Fixed Point Opportunistic Routing (FPOR) protocol [62] tried to reduce the delay experienced by the data packets in the network. This device utilized the probability of devices coming in contact with each other to generate the candidate relay set. Contact probabilities of every device were estimated in the network and this was given the prime importance in FPOR protocol. This protocol suffered from low performance in Dynamic MANETs with extremely mobile devices. Also the protocol was unable to efficiently manage the communication holes in the network.

Delegation Forwarding protocol [63] also used the contact probabilities of devices in the network to make the routing decisions. It worked on the theory that frequently encountered devices would be better forwarders in the network. This protocol was less complex and reduced some of the overhead caused by earlier OR protocols. This was one of the better protocols used in communication in disaster recovery operations. The protocol however had issues with bandwidth usage and storage in the network. Duplicate messages generated in the network reduced the performance of this protocol in Dynamic MANETs with highly dynamic devices.

OR-Flooding [64] protocol was designed to work in low duty cycle networks. Delay information at the devices was used by this protocol to make forwarding decisions in the network. The major advantage of this protocol was in low energy consumption compared to previous OR protocols. Also this flooding technique had less delay compared to all previous flooding techniques in Dynamic MANETs with dynamic devices. However, this protocol could only be used in duty-cycled stationary networks.

Optimal probabilistic forwarding protocol [65] tried to improve on the delivery rate in the network by generating multiple copies of the data packet and allowing the sender device to send these copies to many potential forwarder devices in the network. This protocol could achieve better throughput compared to previous protocols, but with many issues and limitations. The major issue with this protocol was the large amount of duplicate messages generated in the network leading to increased congestion and battery usage. These limitations made this protocol unsuitable for dynamic MANETs with extremely mobile devices.

Encounter Based Routing (EBR) protocol [66] set an upper limit on the amount of duplicate copies that can be generated from a data packet. The main objective of this protocol was to solve the major issue of redundant data packets in the networks. Working of EBR is based on the encounter probabilities of devices in the network and this protocol assumes that the devices that encounter frequently are better forwarders for any data packet in the network. EBR had better performance compared to Delegation Forwarding in Dynamic MANETs. Although EBR was able to limit the number of duplicate packets generated in the network, it was unable to improve upon the QoS of data transmission in networks with extremely mobile devices.

One of the latest OR protocol in this category, MaxOpp [67] was proposed by Bruno and Conti, (2010). Although this protocol was a much improved version compared to all previous protocols, this protocol too could not offer better performance in terms of Quality of Service in Dynamic MANETs.

Table 4 summarizes the issues and challenges faced by various probability based OR protocols in Dynamic MANETs. Due to numerous limitations of probability based OR protocols the focus shifted to cross layer based protocols that utilized information from more than one layer. Information from the Network layer, MAC and Physical layers were combined to improve the QoS in data transmissions. The next section explains the working of cross layer based OR protocols in Dynamic MANETs.

Table 4: Issues and Challenges with Probability Based OR Protocols in dynamic MANETs

Protocol	**Metric**	**Coordination Method**	**Issues and Drawbacks**
FPOR	Delay based	Timer	Low performance in Dynamic MANETs. Redundant messages. No efficient mechanism to handle communication holes in the network.
Delegation Forwarding	Quality	Overhearing	High bandwidth required. Increased storage. Redundant messages.
OR-Flooding	Delay	Overhearing	Only works with duty-cycled stationary networks.
OPF	PDR	Ticket Based	Large amount of duplicate messages. Increased congestion. Increased battery usage.
EBR	Delay	Overhearing	Low QoS with increasing mobility of devices.
MaxOpp	ETX	Overhearing	Low QoS with increasing mobility of devices.

7. Cross Layer Based ORPs

Cross layer based OR protocols utilized information from Network, MAC and Physical layer to improve the efficiency of OR protocols in Dynamic MANETs with extremely mobile devices. This information was used to generate the candidate sets and to prioritize the forwarder devices. Some of these cross layer based protocols offered better performance compared to the previous three categories of OR protocols in Dynamic MANETs.

PRO protocol [68] used information from the network layer along with data from MAC and Physical layers to improve the QoS of OR in Dynamic MANETs. The protocol used Link Quality Indicator (LQI) and Received Signal Strength Indicator (RSSI) as the major indicators for candidate set selection and prioritization. The protocol measured the quality of various links in the network and eliminated the low quality links. This protocol utilized overhearing property of the neighboring devices as the coordination mechanism among the devices in the network. The transmission link that had the maximum RSSI value was then selected to forward the data packet to the destination. PRO protocol did not offer techniques to handle communication voids in the network and had high overhead in Dynamic MANETs.

ILOR protocol [69] used the information on link quality towards the destination in prioritizing the candidate set of devices and in selecting the best forwarder device in the network. The best forwarder device was selected using the link quality information towards the destination in this protocol. The major issue with this protocol was that the data packets can be relayed only up to two hops in the network. This protocol was thus highly unsuitable for large ad hoc networks with extremely mobile devices.

Simple and Practical Opportunistic Routing (SPOR) [70] was an interference aware cross layer based OR protocol that used acknowledgements for each data transmission to avoid duplicate packet retransmissions in extremely mobile networks. The major limitation with SPOR is that the performance of this protocol comes down if the path of data transmission consists of more than four hops. This protocol was therefore highly unsuitable for large ad hoc networks with many mobile devices. Numerous limitations prevented this protocol from being used in real time applications.

Energy-Efficient Opportunistic Routing protocol (EEOR) [71] was aimed at minimizing the energy usage of devices in the network. This protocol used information about transmission power of devices in the network and was mainly used in wireless sensor networks. This protocol suffered from low packet delivery rate in the network. This protocol could not offer better QoS in Dynamic MANETs with extremely mobile devices.

Cooperative Opportunistic Routing protocol (CORMAN) protocol [72] used information about the position and speed of devices in the network to improve on previous OR protocols in Dynamic MANETs. The protocol operated in similar fashion to the earlier proposed cross layer based PRO protocol. This protocol used Link Quality Indicator (LQI) and Received Signal Strength Indicator (RSSI) as the major indicators for candidate set selection and prioritization. This protocol made use of a realistic propagation model in the network. CORMAN achieved better throughput compared to previous OR protocols, but its performance came down with increasing mobility of devices in the network.

The protocols Parallel-OR [73] and QoS Oriented Opportunistic Routing protocol (QOR) [74] tried to increase the throughput of data transmission in the network by using information on signal power from lower layers. Both the protocols exploited multiple paths to the destination. QOR protocol used a token based coordination method among the devices in the network. The major drawback of these protocols was that they never took account of the increasing signaling overhead in data packet transmission in the network and gave moderate performance with increasing mobility of devices in the network. They worked well with sensor networks but could not offer better QoS in Dynamic MANETs.

Context Aware Opportunistic Routing (CAOR) protocol [75] offered much better performance compared to all cross layer based protocols in Dynamic MANETs with extremely mobile devices. CAOR used coding gain information to increase the delivery rate in the network. The coordination mechanism used was based on packet overhearing in the network. CAOR achieved higher data delivery rate compared to all the previous protocols in Dynamic MANETs with extremely dynamic devices. But the performance of this protocol came down with increasing mobility of devices in Dynamic MANETs. One of the latest cross layer based protocol ORW, [76] was mainly targeted to achieve energy efficiency for wireless sensor networks. The protocol achieved in obtaining lower delay in data transmissions, but offered low QoS in Dynamic MANETs with extremely mobile devices. Most of the cross layer based protocols was often aimed to minimize the energy usage in the network and was only suitable for wireless sensor networks. Most of them offered low QoS in Dynamic MANETs with extremely mobile devices. Table 5 summarizes the issues and challenges with cross layer based protocols in Dynamic MANETs.

Table 5 Issues and Challenges with Cross Layer Based OR Protocols in Dynamic MANETs

Protocol	**Metric**	**Coordination Method**	**Issues and Drawbacks**
PRO	RSSI	Overhearing	Could not handle communication voids in the network High time overhead
ILOR	SNR	Contention based	Packets can be relayed up to two hops only
SPOR	Interference	ACK + Overhearing	Performance comes down if the path consists of more than four hops
EEOR	Energy	Overhearing	Low performance in extremely mobile networks
CORMAN	Hop count	Overhearing	Performance came down with increasing mobility of devices in Dynamic MANETs Time Overhead
QOR	Link Quality	ACK + Overhearing	Performance came down with increasing mobility of devices in Dynamic MANETs High Overhead
Parallel-OR	SNIR based	ACK	Performance came down with increasing mobility of devices in Dynamic MANETs Redundant packet transmissions.
CAOR	Coding Gain	Data Overhearing	Performance came down with increasing mobility of devices in Dynamic MANETs High Overhead
ORW	EDC	ACK + Overhearing	Performance came down with increasing mobility of devices in Dynamic MANETs High Overhead

Due to numerous limitations of cross layer based protocols in Dynamic MANETs, the focus shifted to incorporate various optimization techniques in already existing OR protocols. The next section explains the working of optimization based OR protocols in Dynamic MANETs.

8. Optimization Based ORPs

Optimization based ORPs tried to optimize the candidate set selection and prioritization in OR using various mathematical techniques like graph theory, machine learning etc. Each of the protocol proposed in this category tried to improve on the basic building blocks of OR in Dynamic MANETs.

Least Cost Opportunistic Routing (LCOR) [40] is one of the best optimized protocols proposed in this category. This protocol helped to find the optimal candidate set for any source device in dynamic environments. But the major problem with this protocol was the increased number of duplicate data transmissions in Dynamic MANETs with extremely mobile devices.

Consort [77] and OMNC [78] optimization based OR protocols also tried to find out the optimal candidate set in the network. These protocols also aimed to reduce the time overhead caused in the network. But both the protocols couldn't offer optimal paths to the destination and often suffered from serious performance issues with rising mobility of devices in the network.

Adapt-OR [79] was an adaptive ORP that introduced a dynamic learning approach to improve the performance of OR in extremely dynamic ad hoc networks. The protocol introduced a new learning frame work for the network through which the details of various connections could be learned. The protocol had major issues with the management of control packets in the network and was often unable to discover the best path to the destination device in Dynamic MANETs

Optimization based OR protocol, PLASMA [80] targeted to improve the performance of routing in wireless mesh networks. PLASMA ensured that every device in the network was linked to more than one gateway in the network. PLASMA then used a variation of the Bellman Ford algorithm to compute the optimal paths from the source to the destination device in extremely dynamic networks. PLASMA improved on the throughput offered in the network but was unsuitable for highly scalable networks.

Time-sensitive Opportunistic Utility-based Routing protocol (TOUR) [81] aimed at reducing the delay of data transmission in the network. The protocol selected potential paths that offered much lesser delay in data transmission. But the protocol could not improve on the delivery rate and throughput of data transmission in the network and suffered from many problems in Dynamic MANETs.

Multi-constrained Any Path (MAP) protocol [82] used optimization techniques similar to the Dijkstra's algorithm to compute the optimal path to the destination. Although this protocol had a number of advantages compared to the previous protocols, it could not guarantee required QoS in Dynamic MANETs with extremely mobile devices.

Localized Opportunistic Routing (LOR) protocol [83] offered good performance compared to previous protocols in Dynamic MANETs with extremely mobile devices. LOR protocol divides the entire network into smaller sub networks based on graph theory. It then used different routing strategies within the smaller sub networks and between these sub networks to achieve better routing performance in highly scalable and mobile ad hoc networks. LOR too could not guarantee required Quality of Service in Dynamic MANETs with extremely mobile devices. Table 6 summarizes the issues and challenges faced by various optimizations based OR protocols in Dynamic MANETs.

Table 6 Issues and Challenges with Optimization Based OR Protocols in Dynamic MANETs

Protocol	**Metric**	**Coordination Method**	**Issues and Drawbacks**
LCOR	EAX	Overhearing	Duplicate data transmissions in Dynamic MANETs
OMNC	ETX	Overhearing	Duplicate data transmissions Inaccuracies in finding the optimal paths
Consort	ETX	Overhearing	Duplicate data transmissions Inaccuracies in finding the optimal paths to the destination
Adapt-OR	PDR	ACK	Issues in management of control packets High Overhead
PLASMA	EAX	ACK	Low Quality of Service in extremely mobile networks
TOUR	Delay	Overhearing	Low QoS, High Time Overhead
MAP	EWATX	Overhearing	Performance degradation with highly mobile devices Duplicate messages generated.
LOR	Link Quality	Overhearing	Performance degradation with highly mobile devices

9. Issues and Challenges

Some of the major issues and challenges existing in the current protocols using opportunistic approach are,

Lack of reliability and continuity in data transmissions.

Most of the existing OR protocols suffer from frequent data loss with increasing speed and movement of devices in the network leading to increased delay. Lack of reliable data delivery is one of the major problems faced by majority of OR routing protocols. Also due to frequent data losses, continuity of data transmissions is not maintained. These two important reasons contribute to the low performance of OR protocols in dynamic MANETs.

Redundant data forwarding at the intermediate devices.

A major problem faced by various OR protocols in dynamic MANETs.with extremely dynamic devices is the increasing number of redundant data forwarding at the intermediate devices. OR strategy enabled data forwarding by the best forwarder device only. But due to inefficient coordination methods between the devices, multiple/duplicate retransmissions of the same data packet occurs at various intermediates devices and this leads to increased traffic and congestion in the network. This is a very vital problem contributing to the below par performance and Quality of Service of OR in dynamic MANETs. Further, this duplicate forwarding increase at an alarming rate with the increase in speed and movement of the wireless devices in the network.

Time overhead caused by packet retransmissions.

Time overhead caused by frequent packet retransmissions is another major problem existing in OR protocols. Although many protocols have tried to reduce the timing overhead, viable solution is not available yet. Most of the solutions proposed had a number of limitations and couldn't be practically used in applications with OR.

Inefficiency in handling communication voids.

One of the major problem faced by almost all existing OR protocols in dynamic MANETs. is the inability in handling communication holes in the network. Communication holes or communication gaps can lead to many problems in routing of data packet between the devices in the network. Most of the existing protocols have found it difficult to achieve good performance with communication holes in the network. Efficient techniques to handle communication hole are still unavailable in OR protocols.

10. Conclusions

The paper discussed the working of the latest opportunistic routing protocols in highly dynamic ad hoc networks and highlighted the issues and challenges faced by them. All the existing protocols proposed for dynamic ad hoc networks were classified based on their work. Each of the protocols were discussed in detail along with their issues and drawbacks. This study would help researchers in developing much more efficient and optimal routing protocols for dynamic ad hoc networks in future Further researchers could also explore the possibilities of implementing opportunistic routing in Underwater Sensor Networks [84-85], IoT Networks [86-99] and Vehicular Fog Networks [100-104].

Author Contributions: For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "conceptualization, X.X. and Y.Y.; methodology, X.X.; software, X.X.; validation, X.X., Y.Y. and Z.Z.; formal analysis, X.X.; investigation, X.X.; resources, X.X.; data curation, X.X.; writing—original draft preparation, X.X.; writing—review and editing, X.X.; visualization, X.X.; supervision, X.X.; project administration, X.X.; funding acquisition, Y.Y.", please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

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