A Comprehensive Study And Evaluation Of Any Opportunistic Routing Schemes Requires An Integrated Approach

S. Sandeep Babu[1], B. Santha Kumar[2]
[1]*M.Tech(CSE), Sri Kottam Tulasi Reddy Memorial College of Engineering, Kondair,Andhra Pradesh, India.*
[2]*Asst.Professor, Sri Kottam Tulasi Reddy Memorial College of Engineering, Kondair, Andhra Pradesh, India.*

Abstract

Efficient and reliable routing is an essential issue in Wireless Sensor Networks (WSN). For routing, Wireless Sensor Nodes need to take the specific requirements of the application into account, i.e. in many cases energy-efficiency and maximum lifetime. The need to optimize energy consumption by minimizing the protocol overhead has lead to a vast number of routing algorithms which minimize energy consumption and maximize network lifetime. The utility of the protocol overhead is particularly critical in scenarios with unpredictable mobility of nodes which have to act as multi-hop relays. The problem of the resulting intermittent connectivity is addressed with the opportunistic routing in this paper.

1. Introduction

The first component deals with designing a protocol to perform routing in the network. These designs are mostly adaptations of routing protocols designed for use in wired networks such as the Internet. Traditionally routing protocols were classified according to three primary types: proactive, reactive and hybrid. Recent works have added geographic routing.

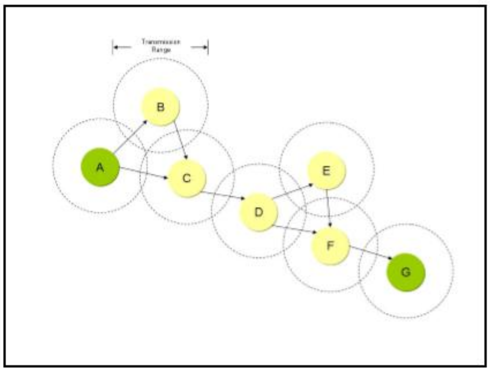

Figure 1: Traditional Mobile Ad Hoc Network Routing

Proactive routing protocols actively finds routes to all destinations in the network regardless of whether they are being used. This makes them more efficient in networks with high utilization, but limits their scalability. In wired networks the scalability problem has been addressed by combining the use of a hierarchical design with route summarization. The most common approach uses the distributed Bellman-Ford algorithm to calculate path costs and choose the best cost. Nodes periodically transmit information on all the destinations they know about. After receiving, nodes update their routing tables with the current known best routes based on the information received in the updates. This type of protocol can cause routing loops in highly variable networks. Destination Sequenced Distance Vector (DSDV) implements this type of routing protocol. It uses sequence numbers for route updates in order to reduce the likelihood of forming a routing loop.

In reactive protocols nodes only calculate routes as they are needed. Reactive protocols have reduced storage overhead in networks with low utilization, but exhibit scaling problems in large or busy networks. Nodes can generate routes as needed by flooding a route discovery packet from the source to the destination and choosing the best route. In Dynamic Source Routing (DSR), the intermediate hops are recorded in the route discovery packet and then the best route is sent backwards to the source.The source then adds the route list to each packet and routing is performed by simply sending to the next hop listed in the routing header. In Ad-hoc On-Demand Distance Vector Routing (AODV), this is modified so the source does not need to put the hop list in the packet. The intermediate nodes maintain a table of active routes through them and know the next hop. Reactive routing protocols suffer from an increase in communication overhead in rapidly varying networks. Routes that are no longer valid need to be rebuilt. A few techniques have been proposed to allow partial route discovery, but still incur significant overhead.

Hybrid protocols attempt to combine the characteristics of both proactive and reactive protocols: nodes proactively maintain routes for all destinations nearby, but reactively generate routes for destinations that are unknown. An example of this is Zone Routing Protocol (ZRP). In ZRP, a global zone radius is set and nodes receive proactive route updates for destinations within this radius. When a source node needs to send a packet to destination outside the zone radius, a flooding algorithm is used to finds a path and routing is performed similar to DSDV.

Geographic routing is able to respond more rapidly to network changes due to the deceased state and use of purely local information. The key behind geographic routing is the assumption that nodes are aware both of their own location and the locations of their neighbors. To send a packet a node must also know the location of the destination. This is reasonable in sensor networks since the positions of nodes already need to be calculated to properly analyze the reported data. There have been a number of geographic protocols proposed. Some use the location information to form a planar graph and walk along the edges towards the destination.

Another approach is to use a greedy algorithm to determine the next-hop node. This means a node chooses the neighbor closest to the destination as the next hop. In arbitrary networks it is possible that there is no node closer to the destination than the current node. For this reason, most protocols specify an alternate routing method for the case when greedy routing fails. It used flooding as the alternate routing method. Greedy Perimeter Stateless Routing (GPSR) was proposed as a solution for wireless networks based on greedy geographic forwarding and uses perimeter routing as a fallback. These protocols perform reasonably in the rapidly varying network environments, but tend to prefer high-loss rate links, which results in reduced throughput and power efficiency. A modification to the greedy algorithm was proposed to incorporate the average packet reception rate (PRR) into the metric used by greedy forwarding, maximizing the product of the PRR with the distance instead of simply using the distance traveled towards the destination for each hop. This provides some improvement but increases overhead by requiring local dissemination of link loss rates and does not consider the effects of fading on the wireless link.

Recently some work in cross-layer design has resulted in a few protocols that take both aspects into account. Opportunistic routing is similar to geographic routing except that the routing algorithm is allowed to choose multiple candidate next-hop nodes which are considered equivalent for routing.

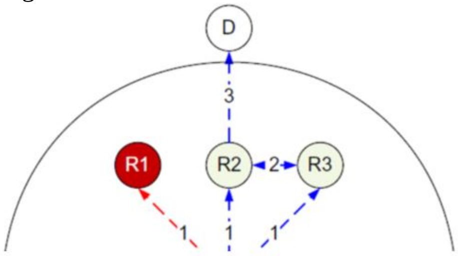

Figure 2: Working of Opportunistic Routing

The actual next-hop node is decided based on the channel from the current hop to the next hop. This makes it apparent that opportunistic routing is simply an adaptation of cooperative diversity techniques. In opportunistic routing, the relays are chosen by the routing layer and then relay selection is used to achieve diversity. In Selection Diversity Forwarding, the transmitter generates a list of candidate relays and transmits it along with the packet. The transmitter chooses the next hop as the candidate that claims to have correctly received the packet that makes the most progress towards the destination. Extremely Opportunistic Routing (ExOR) takes a similar approach, except proposes a recursive multi-stage approach where the candidates consist of all nodes between the current position and destination. Since this method had significant overhead, numerous packets were grouped together in batches and sent simultaneously to amortize the overhead. Opportunistic routing was posed as an optimization problem and the power efficiency was optimized. These protocols suffer increased overhead that significant degrades their performance, reducing power efficiency to less than greedy geographic routing for some classes of networks.

Opportunistic routing exploits the spacial diversity of the wireless medium by involving a set of forwarding candidates instead of only one in traditional routing. This improves the reliability and efficiency of packet relay. Some variants of opportunistic routing, such as ExOR and opportunistic any-path forwarding, rely on the path cost information or global knowledge of the network to select candidates and prioritize them. In the least cost opportunistic routing (LCOR), it needs to enumerate all the neighbouring node combinations to get the least cost OR paths. Another variant of OR is geographic opportunistic routing (GOR) which uses the location information of nodes to define the candidate set and relay priority. In GeRaF, the next-hop neighbours of the current forwarding node are divided into sets of priority regions with nodes closer to the destination having higher relay priorities. Similar to the network layer specifies a set of nodes by defining a forwarding region in space that consists of the candidate nodes and the data link layer selects the first node available from that set to be the next hop node. However, there is no theoretical work on determining the end-to-end throughput bounds of OR. It is not well understood how the selection and prioritization of the forwarding candidates will affect the routing efficiency.

2. Background and Field of Relevance

It has been over two decades since the birth of the world's first commercial cell phone, the Motorola DynaTAC 8000X, in 1983 [Motorola, 2007]. Today, following rapid technological developments, mobile wireless communication technologies have evolved to an unprecedented level. Mobility has penetrated every aspect of people's lives and wireless connectivity has covered every corner of modern society [ITU, 2007]. While people are enjoying the convenience of communication brought by seemingly ubiquitous wireless connectivity such as cellular and WIFI, there are circumstances when network communications face extreme conditions where no existing infrastructure is available. There environments include disaster relief networks, ad hoc information discovery and distribution networks and the ad hoc interplanetary communication network [Burleigh et al, 2003]. In such environments, current mobile wireless communication models do not perform well. This is because current models assume the availability of wireless communication infrastructures and the reliability of connectivity, and are not designed to target extreme networking environments.

On the other hand, while some areas enjoy the benefits of pervasive information access through mobile wireless technologies, other areas are left behind, unexplored and underdeveloped, such as developing regions in Africa. In these cases, the current Internet model of communication is unaffordable because of the cost of infrastructure deployment and the running cost required by telecommunication providers. Alternative methods of connectivity are thus required. New technologies under development that specifically target these issues include the MANET and the DTN (Delay Tolerant Network). In addition, while not born of necessity, MANET and DTN architectures may be utilized by communities who wish to build their own networks for purposes such as toll bypass, entertainment, and community building applications.

Opportunistic routing for multihop wireless ad hoc networks has seen recent research interest to overcome deficiencies of conventional routing as applied in wireless setting. Motivated by classical routing solutions in the Internet, conventional routing in ad hoc networks attempts to find a fixed path along which the packets are forwarded. Such fixed-path schemes fail to take advantage of broadcast nature and opportunities provided by the wireless medium and result in unnecessary packet retransmissions. The opportunistic routing decisions, in contrast, are made in an online manner by choosing the next relay based on the actual transmission outcomes as well as a rank ordering of neighbouring nodes. Opportunistic routing mitigates the impact of poor wireless links by exploiting the broadcast nature of wireless transmissions and the path diversity.

The researchers provided a Markov decision theoretic formulation for opportunistic routing. In particular, it is shown that the optimal routing decision at any epoch is to select the next relay node based on a distance-vector summarizing the expected-cost-to-forward from the neighbours to the destination. This "distance" is shown to be computable in a distributed manner and with low complexity using the probabilistic description of wireless links. The previous studies provided a unifying framework for almost all versions of opportunistic routing such as SDF, Geographic Random For- warding (GeRaF), and ExOR, where the variations are due to the authors choices of cost measures to optimize. For instance, an optimal route in the context of ExOR is computed so as to minimize the expected number of trans- missions (ETX), while GeRaF uses the smallest geographical distance from the destination as a criterion for selecting the next-hop.

The opportunistic algorithms proposed depend on a precise probabilistic model of wireless connections and local topology of the network. In a practical setting, however, these probabilistic models have to be "learned" and "maintained." In other words, a comprehensive study and evaluation of any opportunistic routing scheme requires an integrated approach to the issue of probability estimation. Authors provide a sensitivity analysis for the opportunistic routing algorithm given. However, by and large, the question of learning/estimating channel statistics in conjunction with opportunistic routing re- mains unexplored.

3. Simulation Model

In this section, the simulation model of the new opportunistic routing protocol is introduced. This model is implemented in the OPNET simulator. The task analysis describes the task of this master thesis. The whole model is analyzed in detail from the structural, opportunistic routing and programming points of view.

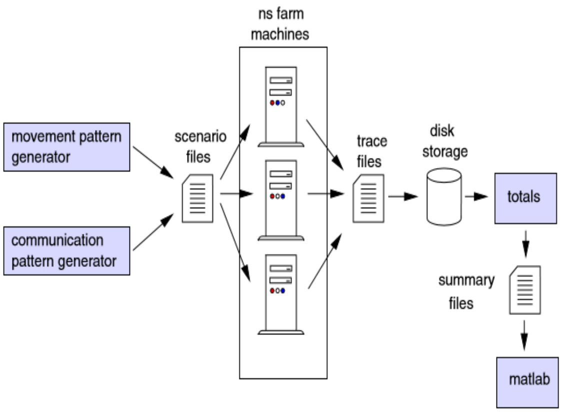

Figure 3: Overview of Simulation Methodology

In order to investigation and validate our hypothesis of OCI, different DTMANET scenarios need to be tested using a simulation approach, so that message delivery ratio, delivery latency, message duplication overhead and other metrics can be evaluated quantitatively. In the following sections, four of the existing network simulators are introduced, and their suitability for supporting the OCI concept discussed, using the following criteria:

1) To which network architecture is the simulator targeted?
2) Which protocols does the simulator support?
3) Does the simulator satisfy the requirements of the OCI hypothesis?
4) Is the simulator extensible and open for modification to suit new needs of OCI?

In addition, the quality of documentation and ease of use of the systems reviewed also affected the choice of simulation environment.

3.1 Existing Simulators

During the course of this research, four of the existing network simulators were investigated for their suitability as testing environments to support the research of OCI. They are NS2 [Johnson et al, 1999], GloMoSim [Nuevo, 2004], QualNet [Kurkowski et al, 2004] and OPNET [Haq et al, 2005]. From the investigations, the following observations were made.

These simulators are designed to simulate a fixed wireless network with limited extension to an ad hoc mobile network. The simulation focuses on low-level network performance such as packet throughput and drop rate, while the research of OCI requires a higher level benchmark such as average delivery rate, average delivery time, and overall message duplication number.

Among the four network simulators a range of routing protocols are supported, which include DSR [Johnson et al, 2004], AODV [Schumacher, 2004], DSDV [He, 2002] and TORA [Bertsekas, 2002], AODV+ [Chin, 2003], AODV-UU [Wiberg, 2003], MAODV [Zhu et al, 2004], ODMRP [Lee et al, 2002], SEAD [SEAD, 2007], ADMR [Jorjeta et al, 2001], ZRP [Ray, 1999], WRP [Royer et al, 2005], Fisheye [Yang et al, 2005] and LAR [Ko et al, 2004]. Although the listed routing protocols are mobile and ad hoc in nature, they do not support delay tolerant communication and none of them supports opportunistic routing.

All four simulators support third-party extensions. However, it became evident through our investigations that extending an existing general-purpose network simulation tool was not an ideal approach. Support for the delay tolerant and opportunistic routing aspects of the study were not natural bedfellows with the base simulation engines designed with more conventional network interaction in mind, and the extension proposals soon took on unattractive levels of clumsiness. The general-purpose nature of the existing network simulators also made the hiding of lower level detail to achieve a level of abstraction, well matched to the DTMANETs, difficult.

3.2 OCI-SIM

It is clear that a simulator targeting DTMANET opportunistic routing simulation is needed. To date, there is no existing network simulator which fits the requirements. Therefore, we developed OCI-SIM. OCI-SIM is designed specifically for delay tolerant communication simulation. In OCI-SIM, communication payloads are defined as messages rather than packets as they are in existing simulators. The support for opportunistic routing protocols is integrated into the core design. The benchmark parameters are defined to suit the high-level system evaluation. In addition, OCI-SIM provides a wide range of useful functions such as simulation automation, opportunistic filtering, a mobility model and device customization, data analysis and routing visualization.

4. Examples of Opportunistic Routing Schemes and Comparison

Nowadays, the deployment of static multi-hop wireless backbones - called wireless mesh networks - is getting increased in different application environments. In these networks, the utilization of the routing protocols is very important to the forwarding process of a data packet.

These protocols are based on shortest-path forwarding strategies, where packets traverse the minimum-cost paths in order to reach the destination. However, pre-computing paths are not always the best solution to adopt, especially when it comes to deal with cannel conditions' unexpected variations and loss links. Due to these reasons, opportunistic routing is seen as a new paradigm that comes out with new solutions. For example, the property of receiving the same packet by multiple nodes is a good way to experience different channel conditions.

Opportunistic routing can combine many weak links into one strong link, because it is based on hop-by-hop route construction.

4.1 Examples

4.1.1 MaxOPP

In order to know the set of forwarding nodes, several opportunistic routing protocols defer the hopes' selection until the reception of the packet. However, some protocols such as ROMER and MaxOPP, avoid this approach.

ROMER is based on credit-based forwarding that builds a mesh of forwarders centered on the minimum-cost path. And, MaxOPP - the protocol studied in this paper - is a new opportunistic routing protocol used in WMNs. It does not adopt the pre-computed forwarders list, and does not oblige any selected node to participate in the transmission process, during pre-assigned time windows.

MaxOPP approach consists in selecting the best forwarders only after the reception of the packet, and the selection criterion is the opportunistic throughput gain. Actually, it adjusts the route at runtime, in order to choose the one that minimizes the expected cost path, and provides the opportunistic gain. By this way, MaxOPP can adapt the forwarding process to variations of channel conditions, in an opportunistic way. MaxOPP can also control the redundancy, by generating multiple nodes as receivers for each data packet, and those receivers can be used as alternative forwarders. To more understand the MaxOPP forwarding process, we need to know some notations: *Cost(p)* represents the cost of delivering a packet on a path p, according to the chosen routing metric. *Ps,d* is the Minimum Cost Path from *stod*. In consequence, *Cost(Ps,d)* is the cost of delivering a packet, on the Minimum Cost Path (MCP) from *s* to *d*.

Let *i = Ps,d(k)* be the kth intermediate router on *Ps,d*. *cost(Ps,d;k)* is the remaining portion of the MCP from *s* to *d* after *k* hops. Due to the isotonicity property (it determines if an efficient algorithm can be used to find minimum-cost paths) of the routing metric, we have : *cost(Ps,d;k) = cost(Pi,d).*

Now, let suppose that a packet is transmitted from a source s in direction of a destination d, in k wireless hops. Based on the above notation, and in order to determine if a node j can be a forwarder, MaxOPP uses the following opportunistic gain:

$$OGsd(j,k) = cost(Ps,d;k) - cost(Pi,d)$$

If the node j is chosen to be a forwarder, the value of *OGsd(j,k)* is granted to the packet. In order to know if a transmitted packet is forwarding on a shorter path than the long-term minimum cost path, a gain ration is used. When this gain ration's value is greater than or equal to Gama, the node j can forward the packet received from the node l, after k hops:

$$ORs,d(l,j,k) = OGsd(j,k)/OGsd(l,k-1) >= Gama$$

Gama is flexible and does not have a precise value. It can be a function of the distance between the source and the destination for example. A node j will try to forward a data packet received from node I, if *: OGsd(j,k) > 0 and ORs,d(l,j,k) >= Gama > 0.*

In order to avoid duplication, MaxOPP implements the overhearing process; every node stores the sequence numbers of its received packets in its transmission buffer. When it receives a duplicated packet, it discards it. In consequence, every packet is forwarded at most once, by the same node. However, the same packet can be received by multiple nodes.

MaxOPP is also based on end-to-end acknowledgments that are sent from the destination to the source. Its role is to recover lost packets not received by the destination. The MaxOPP performance evaluation is done in different network scenarios, using the ns-2 simulator. It is compared to OLSR, another protocol that forwards data packets over minimum-cost paths. The first evaluation is done with the single flow, on a linear chain topology. The 4-hop chain topology has a delivery rate equals to 1, in all 1-hop links. In this case, the packets can easily get lost when there are collisions.

The number of hops and the delivery rate are varying. Let us explain than the delivery rate gives us an idea about the packet loss probability. First of all, we observe that, fewer hops there are better the protocols are doing. Otherwise, their throughputs gains are higher, because when the number of hops is increased, it means that the networks get complex. When we compare MaxOPP to OLSR, we always see that MaxOPP is doing better in all considered scenarios. Generally, when the delivery rate is close to 1, protocols have less packets losses due to the use of less links, by the shortest path routing.

Concerning OLSR, we notice that it suffers from throughput degradations when it comes to intermediate delivery rate. This situation is due to the frequent route flapping. When we compare MaxOPP and OLSR in a linear topology with variation of the hops' number and a fixed delivery rate equals to 0.5, we see clearly that MaxOPP is still doing better that OLSR, and the throughput gain is getting decreased when the number of hops gets increased.

The evaluation of MaxOPP's performance is done in a 5x5 grid-based network topology. The delivery rates for 1-hop links are equal to 1 (perfect), and the delivery rates for 2-hop links are equal to 0.5. Every node presents either the source or the destination of a single flow. MaxOPP is doing better with one flow. However, when the number of flows is increased, the network's congestion arises, and the efficiency of MaxOPP decreases because a packet is allowed to be forwarded by multiple nodes at each hop, which may exacerbate congestion conditions.

The confidence intervals are high, due to the fact of choosing flows randomly and the possibility of having difference between flows' lengths and spatial distribution. Generally talking; compared to traditional routing based on the shortest path, MaxOPP proves its ability to be adapted to the variations of network conditions, and the results show its throughput improvements. However, when the number of flows increases, MaxOPP suffers from performance degradations. That is why, another opportunistic routing protocol is proposed. It can support multiple simultaneous flows by combining different conditions.

4.1.2 packetOPP

Wireless Mesh networks (WMNs), are static multi-hop wireless backbones that are nowadays, deployed in different environments. In WMNs, opportunistic routing is a new routing paradigm that has these properties:

- The selection of the next forwarding node is deferred after packet reception,
- The nodes that overhear a packet transmission, participate in the forwarding pro- cess.

PacketOPP is an opportunistic routing protocol that gathers randomized opportunistic forwarding with opportunistic packet scheduling. PacketOPP is a non-scheduled protocol, which is used in different network scenarios. Its principles are:

- Every node has multiple queues (Local Queue and Forwarding Queue) that separate local traffic from forwarded traffic (packets received from other nodes).
- In Forwarding Queue, transmitted packets with the highest opportunistic gain, have a higher priority.

However, PacketOPP should avoid the starvation of some packets that present lower opportunistic gains. In PacketOPP design, tree issues are discussed:

- In forwarding decision, the opportunistic ratio determines if a receiver can be a forwarder. In scheduling packet transmissions, PacketOPP forwards the packet with the best opportunistic gain. When a node becomes forwarder, it removes duplicate received packets. Actually, it knows by comparing that packet with the packets it has in its forwarding queue.
- In prioritization of channel access, the channel access get higher when a packet's potential gain is also high.
- In loss recovery, the destination nodes ask the source nodes to retransmit the lost packets. It is done by sending periodic end-to-end unicast acknowledgement packets, in the shortest path.

PacketOPP's performance evaluation, is done in different networks scenarios, using the ns-2 simulator. It is compared to ROMER and MaxOPP, which are two non-scheduled opportunistic routing protocols. ROMER, is a protocol that is based on limiting a packet's transmissions number, before getting the destination. MaxOPP, is a protocol that is based on controlling the forwarding process's redundancy, by using a packet's opportunistic throughput gain.

The simulation starts first with a linear chain topology with single flow, and then it is done in 5x5 grid topologies with multiple simultaneous flows. In single flow scenario, the results show for a flow traversing a 7-hop chain topology versus the packet delivery rate, that PacketOPP's throughput is approximately equal to MaxOPP (because they share the same principles in choosing the node that can be allowed to be a forwarder), and higher than ROMER and OLSR. Numerically, the maximum throughput gain exceeded 250% for ROMER and 600% for OLSR.

4.2 Comparison

It exists different routing schemes with different functionalities: In traditional routing, the routing schemes deal with wireless links as point-to-point wired links, and pre-select a specified relay node at each transmission, according to different metrics. The traditional routing does not utilize overhead data packets. The transmission re- liability here can be higher, and the transmission range can be maximized, when the overheard packets are well utilized. When it comes the selection process, the opportunistic routing is characterized by its dynamic selection, which is not the case of the traditional routing. In fact, this major characteristic of choosing the next relay dynamically from multiple relay candidates, is not exclusive to the opportunistic routing. There are some routing schemes called selection diversity, based on the same characteristic of choosing dynamically the next relay, however there is a difference; the selection diversity schemes is based on the dynamic selection of the relay from candidates, and then, the data packet is sent to the chosen relay, by unicast.

In multiuser diversity forwarding (MDF), the selection of the next relay is based on current link conditions. Actually, a probe is first sent by broadcast before each trans- mission, to relay candidates. Then, according to the received probe, a candidate can determine the current link quality, and in consequence, can respond with a probe reply. After that, the sender can select the relay that has the best quality by comparing the replies it gets from candidates.

Compared to traditional routing, these selection diversity schemes have the same behaviour, when it comes to overhead packets that they do not utilize. Compared to opportunistic routing, the selection diversity schemes have also multiple relay candidates. However, the difference from the opportunistic routing is the fact of being not opportunistic in nature. Experiment results and theoretical analysis have shown that the opportunistic routing is performing better than traditional routing, especially when it comes to high loss of links.

Generally talking, the main difference between traditional routing, opportunistic routing and selection diversity are, the time of relay selection and multiple relay candidates. The opportunistic routing is the only routing scheme that uses overhead data packets, and it is based on the dynamic selection of the next relay from multiple candidates after data transmission. And the data transmission is done by broadcast to all candidates.

5. Conclusion

Due to the increasing use of Internet by users everywhere in the world, the need of having low-cost, higher data rates and easy-to-deploy connectivity is really important. That is why the deployment of wireless multi-hop networks is also getting promoted, and become more and more popular.

In order to ensure robust communication through the wireless multi-hop backbone, routing is essential. And, there exists a lot of routing schemes whose goal is to ensure a long-term stable optimality for some performance metric, by looking for minimum cost paths.

To deal with these limitations, new innovative routing approaches have been recently proposed; the opportunistic routing. They can be seeing as valuable alternative to classical routing.

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