# Opportunistic Routing: Opportunities and Challenges

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*Abstract*—**During the past few years Opportunistic Routing (OR) gained a lot of attention as a way to improve the performance of wireless multi-hop Ad-hoc networks and wireless sensor networks. OR takes advantage of the broadcast nature of wireless communications to improve transmission reliability and throughput by forwarding data through a set of paths instead of one best path. In this paper we demonstrate the efficacy of OR by comparing it with traditional wireless routing protocols. Concurrently we also outline several vital design issues that needs to be considered by OR protocols to make it more effective and deployable. Finally, based on our extensive analysis we provide a generic framework to develop OR protocols for wireless ad-hoc and sensor networks.**

*Index Terms*—**Forwarder list, opportunistic routing, prioritization, selection**

## I. Introduction

Traditional routing protocols for multi-hop wireless networks preselects some fix paths and send the packets to next hop nodes. These protocols produce a good result when applied to wired networks or infrastructure based wireless networks. However, for infrastructure less wireless network scenarios like wireless ad-hoc and sensor networks this kind of protocols does not incur good quality and reliability as wireless medium is unstable by nature. Additionally, duty cycles of the nodes make them less available for routing. For these reasons a new kind of routing protocol, named Opportunistic Routing (OR) protocol gained attention. In this paper we highlight the major issues in OR protocol and provide possible research directions to address these issues.

The paper is organized as follows. In section II and III we review the design issues and principles of wireless networks and OR protocols. In section IV we analyze the major proposed OR protocols and highlight their limitations. We reinforce our analysis with actual results in section V. In section VI we give directions as to resolve these potential issues and discuss future research issues. The concluding remarks are given in section VII.

## II. Design Issues

Wireless networks have peculiar characteristics and restrictions. Performance of a wireless routing protocol will basically depend upon how these attributes are addressed. In this section we briefly review the wireless routing issues and examine the OR protocol vis-à-vis these issues.

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### A. Wireless Routing Issues

A general design goal for any routing protocol is to increase the throughput while minimizing the packet loss rate. In ad-hoc wireless networks nodes are assumed to be mobile; that is nodes change their physical location with time. Due to this movement, topology of the network will change frequently. Routing algorithms for such networks thus need to consider a dynamic topology. Link quality is another challenging factor as fading and high error rate in wireless medium affect the routing of packets. For this reason the manner in which packet delivery failures are handled will strongly influence the performance of wireless routing protocols.

In wireless networks an additional goal is to prolong the connectivity of the network by employing energy management techniques. The nodes may be battery powered and have limited amount of energy stored. This will be particularly true for sensor networks where nodes are usually left unattended after deployment. Routing algorithm for such networks need to monitor the stored energy of node and route packets accordingly. Wireless networks in general and sensor networks in particular have limited capacity in terms of bandwidth, memory and computation power. These factors also need to be considered while designing routing algorithms for wireless networks.

## III. The OR protocol

Multi-hop wireless networks have two major differences over the wired networks which have been exploited by OR protocols. Firstly, all pairs of nodes are one-hop neighbors, i.e. all the nodes can sense the transmissions of all other nodes, may be with a very low probability of sensing the packets successfully. Secondly, all the packets in wireless networks are broadcast, i.e. all the neighboring nodes can sense the packets without depending upon whether they are intended for it or not.

The basic idea behind how an OR protocol works is as follows. In a network scenario a source node wants to send a batch of packets to a destination node a few hops away. There will be many nodes between the source and the destination nodes, among these nodes only a subset will try to participate in the routing process. To decide the subset the nodes will run a decision making process before starting transmission. Now the source node starts transmitting the packets. If the destination node does not receive a packet in the first transmission, the node in the subset which is closest to the destination will broadcast the packet if it has received it successfully, otherwise the next closest node will try. The idea is to identify a network metric such that the packet will move closest to the destination in each successive transmission. This process of forwarding the packet will continue till the destination node receives the packet successfully. Thus the two main steps in an OR protocol are (i) selection of the forwarder list and (ii) prioritization among these forwarders. The performance of an OR protocol will depend on how these two steps are performed. The routing issues which we have highlighted earlier needs to be incorporated in these two steps.

## IV. Analysis of OR protocols

OR protocols are a relatively new class of wireless protocols. In the past few years researchers have proposed quite a few OR protocols. Liu *et. al.* [1] have recently attempted to classify the current OR protocols. Their classification is mainly based on the design structure and working principle of the protocols, viz. hops count, packet delivery ratio, node power level etc. In this section we examine the current OR protocols in terms of the wireless routing issues and investigate the deployablity of the protocols in an actual wireless network. To the best of our knowledge this is the first such attempt to study OR protocols in the light of wireless routing issues.

### A. Network Model

The network is modeled as a graph $G = (V, E)$ where $V=(v_1, v_2, \ldots v_m, \ldots v_n)$ be the set of nodes and E be the set of edges. A link $(v_i, v_j)$ is in $E$ if $v_j$ is in the transmission range of vi. In fig. 1 we show a simple wireless network with Packet Delivery Ratios (PDR) indicated along each link in percentage. In this figure the neighbors of the node $v_1$ are $(v_2 \ldots v_{m+1})$; the next hop neighbor for $v_2$ is $v_{m+2}$ and so on.

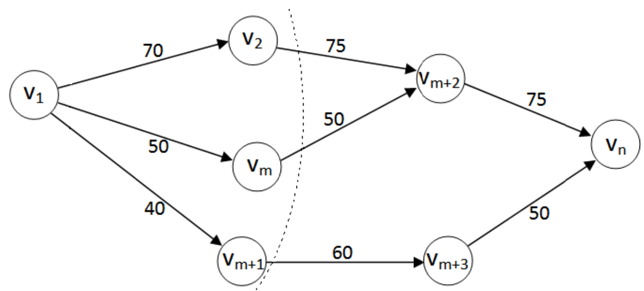


Fig. 1. Simple network with packet delivery ratios.

### B. Mobility Model

Mobility is a very important feature in infrastructure-less networks and to an extent in wireless sensor networks too. Therefore, in the design of a new wireless routing protocol one key simulation parameter is node mobility. Due to mobility a valid route may become invalid and vice-versa. This is true for OR protocols also. Consider the network topology shown in fig. 1. Numbers shown in the figure are packet delivery ratios (PDR) of the edges. PDR of a link is the ratio of the number of successfully delivered packets vs. the number of packets sent through that link, while PDR of a route is the minimum PDR of the links in that route. To minimize the error rate, a logical solution for the sender is to choose the path that has the highest PDR [2].

In Fig. 1 assume source node $v_1$ wants to send a batch of $M$ packets to the destination node $v_n$. The forwarder list of $v_1$ will be the set of nodes $v_2 \ldots v_{m+1}$. Among these forwarders, node $v_2$ will have the highest priority, as the route through $v_2$ has the highest PDR value. In OR protocols, the forwarder list is computed once at the beginning of the transmission and the same forwarders are used for the entire batch of packets. Let $\rho$ be the time taken to transmit a packet. Then for a successful transmission, the network topology should remain unchanged for $\rho M$ time.

Let $s_i$ and $s_j$ be the speed of any two nodes $v_i$ and $v_j$ respectively, where, $v_i, v_j$□$V$. Let the location of the two nodes are $(x_i, y_i)$ and $(x_j, y_j)$ with directions $\theta_i$ and $\theta_j$ respectively. Let $a = s_i cos(\theta_i) - s_j cos(\theta_j)$, $b = x_i - xj$, $c = s_i sin(\theta_i) - s_j sin(\theta_j)$ and $b = y_i - y_j$, where $s_i$ and $s_j$ denote speed of node $v_i$ and $v_j$ respectively. The amount of time the two mobile nodes will remain connected can be estimated using equation 1 [3] where $r$ is the maximum possible distance among the two nodes to stay connected which is the radius of the coverage area.

$$D_t = \frac{-(ab+cd)+\sqrt{(a^2+c^2)r^2-(ad-bc)^2}}{a^2+c^2} \qquad (1)$$

From equation 1, we can see that the expected duration of a connection ($D_t$) between two mobile nodes will decrease if the nodes move at different speeds ($s_i \neq s_j$) irrespective of their direction or the nodes move at the same speed but not in parallel ($s_i = s_j \neq 0$ and $\theta_i \neq \theta_j$). The expected connection duration of the path along node $v_2$, the highest priority path will be the minimum $D_t$ of all the edges along the path. The transmission along this path will be successful if $\rho M \leq D_{t,}(v_2)$. Consider the case where the edge from $v_2$ to $v_{m+2}$ fails after the transmission of the first few packets due to node movement. The OR protocol will not be aware of the change in topology and $v_2$ will still be the highest priority forwarder in the second hop. However, all packets forwarded by $v_2$ will fail. Eventually timeouts will occur and the next priority forwarder $v_m$ will forward the packets. This will happen for all the remaining packets. On an average if half of the packets suffer from timeouts, the performance of the protocol will be severely affected. Current OR protocols select route based on the assumption that the nodes are static.

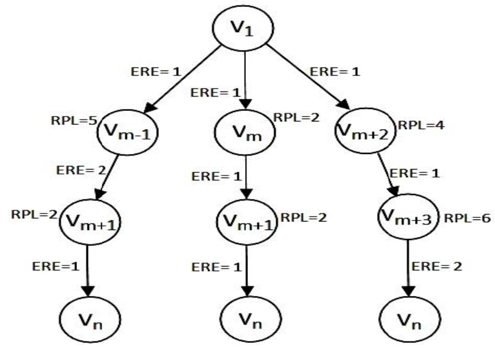


Fig. 2. OR-tree of a network with RPL and ERE values.

### C. Power Efficiency

Power efficient wireless routing protocols will try to consume minimal power to route packets, as well as use the power in a balanced manner such that the lifetime of the nodes are prolonged. Mao *et. al.* proposed a routing protocol EEOR [4] that computes the Expected Transmission Power Consumption (ETPC) for all possible routes and selects the route that has the lowest value which is the sum of the Expected Required Energy (ERE) of all the links in that route.

Kim *et. al*. proposed ORTR [5] for wireless sensor networks to deliver data under time constraints and efficient power consumption. Instead of selecting the route with lowest expected cost it selects nodes with the highest Remaining Power Level (RPL) from an Expected Real-Time Guarantee Region (ERTGR) at each hop which is a geographical region that guarantees the timely data delivery.

In this section we show that a global optimization strategy may reduce the overall lifetime of the network instead of prolonging it if hop-by-hop states are not considered. Let us again consider fig. 1. This network model can be represented by an OR-tree [6] as shown in fig. 2. Suppose we are using a power-aware protocol that considers the minimum energy route (similar to [5]). Let, ERE of a link $v_i \rightarrow v_j$ (the amount of energy expected to be consumed by $v_i$ to send a packet to $v_j$) be represented as $ERE_{ij}$. If there are $n$ nodes in a route ($v_1$ to $v_n$) then we can formulate the total $ERE$ or $ERE_{1,n}$ of the route as,

$$ERE_{1,n} = \sum_{i=1}^{n-1} ERE_{i,i+1}$$

Let's also assume that the set of forwarders of a node $v_x$ is $F(x)$. Now, selection of the highest priority forwarder $v_l$ for hop level $l$ ($l = 1, 2, ...n$) can be represented as,

$$v_l = \max_{\forall i, v_i \in F(l-1)} \{ERE_{i,n} + ERE_{l-1,i}\} \tag{2}$$

Equation 2 shows that such a protocol will select the middle sub-tree as its best route. However, as can be seen from the figure, this route will be able to deliver only two packets where as selecting the right-most sub-tree would have ensured a delivery of three packets.

Again let us consider the same network (fig. 2) to analyze a second power-aware protocol that assign a higher priority to a node with larger RPL (similar to [7]). Let the set of neighbors of a node $v_i$ in the ERTGR is $TGR(v_i)$. Similar to EEOR, we can formulate the selection of the highest priority forwarder $v_l$ for hop level $l$ as,

$$v_l = \max_{\forall i, v_i \in TGR(v_l - 1)} \{RPL(v_i)\} \tag{3}$$

where $v_{l-1}$ is the forwarder selected in the previous hop. Clearly, this protocol will select the left-most sub-tree as the best route which will be able to deliver only two packets. However, as we have stated before, selecting the right-most sub-tree would have ensured a delivery of three packets improving the life-time of the network. From this examination we can conclude that a global or a local optimization criterion may not be the best approach. A hybrid approach can be investigated to prolong the network lifetime.

### *D. Proactive vs. Demand-Based Operation*

Wireless nodes can establish and maintain routes either proactively or reactively. EEOR [4] and ORTR [5] periodically monitor connectivity to peers and compute routes to ensure ready availability of path amongst the active nodes which eliminates the overhead of path discovery. The forwarder list is prepared using this updated table. The main problem with this approach is to determine the frequency of the route updates. If the frequency is low the changes in the network topology will not be accounted. On the other if the route update frequency is high, the overhead to maintain the routing tables will be prohibitive.

Demand-based or reactive protocols, e.g. ExOR [2] and MTS [7], establish path only upon demand. When a node has some packets to send, it tries to find the best possible path and routes the packets along that path. Reactive protocols is usually preferred in mobile ad-hoc networks due to dynamic route discovery policy that reduces the routing overhead for medium to low traffic although it adds-up an overhead time for path discovery.

Both of this approach has its own merits and demerits and which of them will be preferred will depend on the underlying network. Proactive approach will not be suitable for wireless sensor networks due to its large data overhead and hardware limitations to maintain the routing tables.

## V. Performance Analysis

The experiments were performed using the Qualnet 5.0 simulator [9] in a Linux platform. We conducted extensive tests for both static and mobile scenarios to compare it with the traditional routing protocol AODV [3]. In this section we present some representative results.

### *A. Network Description*

All the scenarios were deployed in a 1500 x 1500 meter$^2$ terrain. The nodes were randomly deployed within the specified region. The source node sends a 100KB file to the destination with packets of payload size 1024bytes for both AODV and ExOR. In mobile scenario some of the nodes are assumed to be mobile. Here we have used Random Waypoint Model for the mobility of nodes. For channel fading we used Two Ray model as our path-loss model.

### *B. Performance*

In this experiment the network scenario and distribution of the nodes was done as shown in fig. 1. Node 1 tries to transmit 100 packets of 1024bytes with an interval of 100ms, totaling 100KB of the file to the node 7. The remaining nodes from 2 to 6 act as forwarders.

The performance metric used to compare the protocols was throughput. In fig. 3(a) we compared the results of ExOR and AODV. As can be seen from the figure ExOR gives a 32 percent better throughput than AODV. This corroborates our analysis in the previous sections. The performance improvement in ExOR is mainly because the number of retransmissions is substantially reduced as compared to AODV. A comparison of the re-transmissions is given in fig. 4 where fig. 4(a) shows the results for our representative scenario.

Using the same scenario next we assumed some of the nodes to be mobile. During the course of our experiment we discovered that the performance depends on which of the nodes were mobile. We therefore performed the experiment under two cases. In the first instance we assumed nodes nearer to the destination and in the second instance the nodes nearer to the source are mobile are mobile. The results are shown in fig. 3(b) 1 and 2 respectively. As can be seen the performance of ExOR drop drastically, whereas change in AODV's performance is not significant. We repeated the experiment with a different scenario and the results were identical as can be seen in fig. 3(b) result 3 and 4.

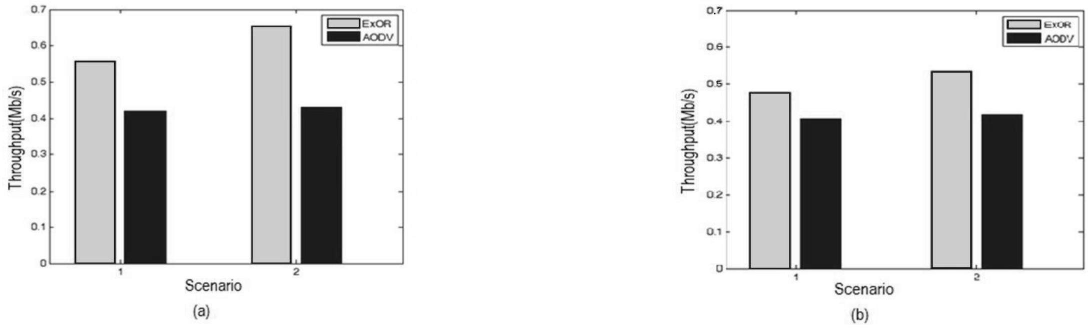


Fig. 3. Throughput of ExOR and AODV. Fig 3(a) shows the results for static scenarios and fig 3(b) shows the result for mobile scenarios.

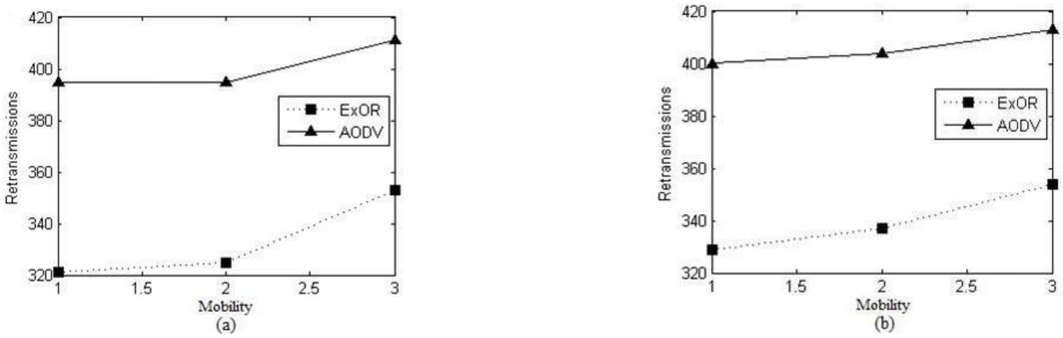


Fig. 4. Number of re-transmissions for ExOR and AODV in static and mobile scenarios.

The explanation behind ExOR's deterioration in performance is as follows. In AODV the packets are forwarded one at a time manner. As the mobile nodes move the links to and from the nodes become weaker with time reducing the reliability of the path towards the end of the transmission. So the packets forwarded at the beginning of the transmission are delivered with higher probabilities. But, But, ExOR forwards the packets in batches which mean the PDRs will be almost same for all the packets in every retransmission. So, all the packets will suffer almost equally. This will cause the mobile nodes near the destination node affect the PDR more than the nodes near the source. The throughput will also depend upon some other factors, like number of forwarders per hop as the other forwarders will reduce the importance of that mobile node for that hop.

Our simulation does not consider the time taken to build the forwarder list in case of ExOR. The measurement of the time taken to select the forwarders will be our future work.

## VI. Open Research Issues

In the previous sections we have seen that the current OR protocols do not consider in detail the characteristics of the underlying network. In this section we summarize the difficulties encountered during implementation of the OR protocols and the possible future research directions.

### A. Metric for Forwarder set Selection

The metric used to select forwarders is the key to the design of an opportunistic routing protocol. Traditionally the metrics used are hop-count, packet delivery ratio, end-to-end delay etc. A single metric may not be able to capture the intricacy of the underlying network. For instance a possible solution to encounter mobility in wireless networks is to use both PDRs as well as expected connection duration ($D_t$) while computing the forwarder list. However, while designing power-aware routing protocols for sensor networks the aim will be optimizing energy consumption and increase network lifetime along with guaranteeing better path for packet delivery. The challenge is to find a metric or a set of metric to select the forwarders for a given network.

A related issue is how to minimize the overhead of computing these metrics, periodically compute these metrics and make it available across the network.

### B. Criteria for Prioritizing Forwarders

In OR the forwarders need to be prioritized and the best forwarder should have the highest priority. The criteria used in prioritization of the forwarders are hop count & PDR [2], geographical location [10], RPL [5] etc. Related to the prioritization of forwarders is the design of the medium access control (MAC). One solution is to use a TDMA approach to maintain a strict coordination among the forwarders, but this not only requires modification of bandwidth but in noisy channels it may lead to wastage of bandwidth and time slots. To eliminate this need many OR schemes use network coding. However, it has certain disadvantages like high computational complexity, ensuring uniqueness of the coefficients etc. High computational power may not be available for all kinds of networks such as sensor networks. The main challenge is for a lower-priority forwarder to learn as quickly as possible that its higher-priority forwarders have failed and initiate re-transmission.

### C. Location Based Routing

In this kind of routing the source broadcast packets and all nodes that hear the broadcast are possible forwarders. These nodes decide their priorities as a forwarder according to source and destination node's location vis-à-vis their own location. The biggest advantage of location based routing is that forwarders list need not be prepared. The nodes only need to know their own geographic location. GeRaF [10] is an excellent example of location based routing. The downside of this protocol is that it randomly selects a forwarder from the nodes in a certain region in every hop. This does not ensure to select the best forwarder that takes the packet nearest to the destination. Further each node must be equipped with Geographical Positioning System (GPS) receivers through which the nodes will observe their current positions that can prove to be expensive. A possible solution to this problem may be to cluster the nodes within a limited geographical area and define their location with reference to a base.

### *D. Bit-Rate Selection*

Wireless protocols have multiple bit rates from which transmitters can choose and agree upon before starting a transmission. Traditional bit-rate selection algorithms require sending packets to a single next hop node; hence the bit-rate is selected by measuring the signal strength to that next hop node. In opportunistic routing a packet is targeted to a group of forwarders. Conventional bit-rate selection algorithms will fail here as it has to decide a common bit-rate amongst all the forwarders. For this reason the current practice in OR is to use a fixed bit rate. Employing an optimum bit rate will greatly influence the performance of OR protocols else all the forwarders may not be able to receive the packets due to disparity in speeds.

### *E. Buffer Size*

In OR protocols forwarders need to store packets which are intended for them. A packet is discarded only when the node makes sure that the packet has safely reached the destination; or a packet from the next batch is received which passively mean all the packets from the previous batches reached destination node properly. Alternatively this means nodes implementing OR protocols need a large buffer size. This requirement can be expensive for wireless mesh and ad-hoc networks but the problem will be more severe for sensor nodes. In OR protocols the lower priority forwarders, being closer to the source node, have higher chances to receive the packets than the higher priority nodes. It means, when a forwarder's buffer becomes full, most of the forwarders having a lower priority are also running out of buffer. The merit of geographic routing protocols over the other OR protocols is they do not need to store the forwarder list inside the packets. This may reduce the size of the packets and better utilize the buffer space but still the number of packets to be buffered is not reduced.

### *F. Quality of Service (QoS)*

In certain applications data needs to be delivered within a certain time period else it becomes useless. OR protocols need to consider bounded latency for data delivery for such time-constrained applications. In such routing protocols timely data delivery will be given more importance than conserving energy or any other factor. Employing QoS features to OR protocols will need to deal with challenges like limited resource constrains and dynamic topology of the networks [11].

### *G. Cross-layer Protocol*

A cross-layered approach to design an OR protocol may improve efficiency as there are many factors that influence the link reliability such as transmission power, frame size, coding technique etc. which are not handled by the network layer. Link reliability may affect the routing efficiency of the protocols. For example, physical layer controls the transmission power level which decides the signal strengths of the links to the neighbors [11]. This affects the packet delivery ratios to the neighbors and also influences the network layer in selecting the for-warders as increasing transmission power level may increase the number of neighbors of a node [4]. On the other hand a cross layer approach may make protocols hardware specific.

## VII. CONCLUSION

Opportunistic Routing Protocols present a new paradigm in the development of wireless network protocols. Due to its intriguing properties, researchers have proposed a number of OR protocols. In this paper we presented a systematic analysis of the current Opportunistic Routing Protocols for wireless Ad-hoc and Sensor Networks. First we highlighted the key characteristics of wireless networks. Subsequently we investigated the performance of the current OR protocols based on these characteristics. We demonstrated the inherent weakness of the presently available OR protocols. Finally we highlight the potential research issues and future directions. We hope this work will motivate researchers to develop efficient and deployable OR protocols.

## REFERENCES


[1] H. Liu, B. Zhang, H. T. Mouftah, X. Shen, and J. Ma, "Opportunistic Routing For Wireless Ad Hoc and Sensor Networks: Present and Future Directions," *Communications Magazine, IEEE*, vol.47, no.12, pp.103-109, December 2009.

[2] S. Biswas and R. Morris, "ExOR: Opportunistic Routing in Multi-hop Wireless Networks," in *Proc.s of ACM SIGCOMM*, Aug. 2005, pp. 133-44.2005.

[3] M. Gerla, L. Chen, Y. Lee, B. Zhou, J. Chen, G. Yang, and S. Das, "Dealing with Node Mobility in Ad Hoc Wireless Network," in *Lecture Notes in Computer Science*, Vol. 3465/2005, pp. 69-10.2005.

[4] X. Mao, X. Li, W. Song, P. Xu, and K. Moaveni-Nejad, "Energy Efficient Opportunistic Routing in Wireless Networks," in *Proc. of the 12-th ACM International Conference on Modeling, Analysis and Simulation of Wireless and Mobile Systems*, October 26-29, pp. 253-260.2008.

[5] J. Kim and B. Ravindran, "Opportunistic Real-Time Routing in Multi-Hop Wireless Sensor Networks," in *24th Annual ACM Symposium on Applied Computing*, March 8-12, pp. 2197-2207. 2009.

[6] M. Lu and J. Wu, "Opportunistic Routing Algebra and Its Applications," in *Proceedings of 27th Annual Joint Conference of IEEE Communication and Computer Society (INFOCOM)*, April 2009, pp. 2374-2382.2009.

[7] Y. Li, W. Chen, and Z. Zhang, "Optimal Forwarder List Selection in Opportunistic Routing," in *Proc. of the Third IEEE International Workshop on Enabling Technologies and Standards for Wireless Mesh Networking*, China, October 12-14, 2009, pp. 670-675.

[8] Qualnet Developer 5.0. http://www.scalable-networks.com/products/qualnet/

[9] C. E. Perkins and E. M. Royer, "Ad hoc On-Demand Distance Vector Routing," In *Proceedings of the 2nd IEEE Workshop on Mobile Computing Systems and Applications*, New Orleans, pp.90-100, 25-26 Feb 1999.

[10] M. Zorzi and R. R. Rao, "Geographic Random Forwarding (GeRaF) for Ad Hoc and Sensor Networks: Multi-hop Performance," *IEEE Trans. on Mobile Computing*, vol. 2, no. 4, pp. 337-48, October 2003.

[11] F. Xia, "QoS Challenges and Opportunities in Wireless Sensor/Actuator Networks," Sensors, Volume 8, no. 2, pp. 1099-1110, February 2008.

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