American-Eurasian Journal of Scientific Research 10 (3): 148-153, 2015
ISSN 1818-6785
© IDOSI Publications, 2015
DOI: 10.5829/idosi.aejsr.2015.10.3.22267

Survey on Opportunistic Routing Protocols in Wireless Networks

A. Arockia Abins and N. Duraipandian

Department of Computer Science and Engineering, Velammal Engineering College, Chennai, India

Abstract: Opportunistic routing is an emerging technology that takes advantage of the broadcast nature of wireless networks. In opportunistic networks, mobile nodes communicate even if a connecting route doesn't exist. In Traditional routing protocols fixed routes are selected for transmission and packets are forwarded for each hop. In dynamic wireless environment, transmission failures occur frequently due to path breaks and demands retransmissions. This unreliable transmission causes additional traffic in the network and waste of network resources and bandwidth. Opportunistic routing promises to be an efficient routing protocol to improve the performance of wireless networks providing increased network throughput and transmission reli-ability. This paper discusses the concept behind opportunistic routing, its classification, metrics used, and efficiency of these protocols.

Key words: Routing • Opportunistic Routing • Wireless Networks • Broadcast • Any Path Routing

INTRODUCTION

IN Opportunistic Routing, routes are built dynamically, while messages are forwarded to the destination. Any node can be used as the next hop forwarding node, provided the packet is delivered at the destination in good form and time. These requirements make opportunistic networks a challenging area in wireless networks. Opportunistic routing is being utilized both in infrastructure and infrastructure-less networks to achieve efficient transmission throughput. Opportunistic Routing uses the broadcasting nature of wireless networks to forward data packets to destination nodes. The forwarded packets can be overheard by the neighbouring nodes and they can forward the packet further. Duplicate transmissions due to path breaks can thus be reduced and transmission reliability can be increased. OR takes multiple relay candidates and performs dynamic relay selection after data transmission. OR selects a set of candidates and broadcasts the packets to these candidates. The best candidate among those that received the packets is chosen as relay node and data is forwarded to this node. It uses a coordination protocol to select the relay candidates. The candidate can be chosen based on specific constraints, like the node that is nearest to the source. The coordination method is used to pick the best candidate to forward packets and to decide whether to forward the overheard packets or not. Instead of selecting a specified relay node at each transmis-Sion, OR broadcasts a data packet to a set of relay candidates. Timer, token, or network coding. Timer based coordination [1] are easy to implement but candidate waiting time causes over- head and duplicate transmissions. Token based coordination reduces such retransmissions, but in the cost of high control overhead. Here, connection must exist between candidates for data to flow between them [2]. Network coding method has no control overhead. Data are grouped into batches and coded before they can be broadcasted. When data is fully received at destination, it is decoded. This coding, decoding introduces certain delay in the network [3].

Opportunistic routing uses hop-by-hop method to select and forward packets. In hop-by-hop forwarder set selection, each candidate can independently determine its forwarder set at each hop along the path to the destination. In End-to-end forwarder set selection, a fixed route from source to destination is first selected and all transmissions done through this route. End-to-end forwarding may lead to duplicate transmissions since non-neighbouring forwarders can make inconsistent de-cisions on packet forwarding. Hop-by-hop method is easy to implement and has good scalability.

Corresponding Author: A. Arockia Abins, Department of Computer Science and Engineering, Velammal Engineering College, Chennai, India.

The rest of the paper is organized as follows. Section II describes the various metrics in candidate selection. Section III provides the several current OR protocols. Section IV presents efficiency of opportunistic routing and section V concludes.

Candidate Selection Metric: A good coordination method should reduce retransmissions and transmission overhead. Coordination involves candidate selection and ordering. The nodes that received the packets are ordered by the constraints and the best node is chosen as relay candidate to forward the packets. Candidates can be selected and prioritized based on metrics like virtual link strength, candidate connectivity, level of contribution and duplicate transmission probability. Factors like coordination overhead and spatial correlation also need to be considered during candidate selection. Metrics used for the candidate selection are hop-count, expected number of transmissions (ETX) [4] and expected transmission time (ETT) [5]. Hop count is the traditional distance vector metric, whereas ETX and ETT are link-state metrics. After the packets are received by the candidates, filtering is done to remove nodes that may decrease the performance of the network. As the candidate list is generally included in the packet header, including more candidates increases the overhead. Number of candidates is limited to minimize the overhead and to reduce duplicate transmissions.

Hop Count: Hop Count can be defined as the number of network devices between the starting node and the destination node or the number of point-to-point links in a transmission path. The source node generates packets that include a field reserved for the hop count. Each time a capable device receives these packets, that device modifies the packet, incrementing the hop count by one. In addition, the device compares the hop count against a predetermined limit and discards the packet if its hop count is too high. This prevents packets from endlessly bouncing around the network due to routing errors. Both routers and bridges are capable of managing hop counts, but other types of intermediate devices are not. Hop count is not a useful metric for determining the optimum network path, as it does not take into consideration the speed, load, reliability, or latency of any particular hop, but merely the total count.

Expected Transmission Count (ETX): The ETX metric calculates the expected transmission count for each link along the path from the source to the destination. ETX studies link loss ratios and interference constraints to find high throughput paths in multi-hop wireless links with least loss ratio and interference are chosen for relay [4, 5]. The ETX metric is better when compared to the hop count for large networks and paths with two or more hops. The ETX considers forward delivery ratio (DF) and reverse delivery ratios (dr) of the link. Forward delivery ratio is the probability of data packet arriving successfully at the receiver and Reverse delivery ratio (dr) is the probability of the acknowledgement (ACK) packet delivered successfully at the sender.

$$ETX\text{-}LINK = 1/(DF * dr) \tag{1}$$

$$ETX\text{-}path = {}^{X}ETX\text{-}LINK \text{ all links in the route} \tag{2}$$

ETX broadcasts probe packets to neighbouring nodes and measures the link loss ratio and inter-link interference. The ETX metric estimates the expected number of tries needed to successfully transmit a packet. ETX finds the route with the highest probability of delivering the packet, rather than the one with the shortest path. It helps to ignore lossy links, links with high interference and also asymmetric links. It is independent of the network load.

Expected Transmission Time: The ETT metric estimates the time required to be success-fully transmit a data packet on a link. ETT can be calculated by adjusting the ETX metric according to the packet size and the transmission capacity of the link.

$$ETT = ETX\ Packetsize/Linkcapacity \tag{3}$$

The source node sends two back-to-back probes to its neigh-Bouring nodes and the neighbouring nodes then determine the Inter-arrival time between the two packets and reports to the sender. Sender estimates link capacity from the delay samples. This method to compute the Expected Transmission Time was proposed by Draves *et al* [5]. Another approach proposed by Aguayo *et al* considers the throughput achieved in broadcast-ing the data packets as data frames and the probability of successful transmission of data and ACK packets.

Expected Anypath Transmission (EAX): EAX captures the expected number of transmissions from the sender to the receiver and helps to determine the contribu-tion of a candidate to the delivery of packets between a node pair. With ETX metric, some candidates do not really make forwarding progress as there can be duplicate transmissions due to poor link conditions. Whereas, EAX metric selects only those nodes that really help efficient packet delivery by considering both the distance and the link quality. EAX chooses it's forwarding candidates more specifically which reduces traffic and provides a more reliable transmission in the network [6, 7]. A potential candidate is considered for inclusion in the set Cs, d only if it reduces the EAX(s, d) by a factor of at least ø, which is configurable parameter. Among such potential candidates, the one that reduces EAX (s, d) the most is added to Cs, d. Opportunistic Routing can be either Topology based or Location based. Location based OR uses location information of the nodes to identify the best nodes to which the messages can be forwarded to. The location information provides the distance between a node and the sender and its distance to the destination node, based on which it can be selected as the next hop node. Whereas Topology based OR provides network information like the shortest distance, connectivity or link quality. This helps to choose candidates that can contribute better in reducing duplicate transmissions in the network.

Opportunistic Routing Protocols

EXOR: Extreme Opportunistic Routing: ExOR is an integrated routing and MAC protocol that increases the throughput of large unicast transfers in multi-hop wireless networks. ExOR integrates routing and MAC protocols [1]. It improves routing performance by utilizing long-range but lossy links. In ExOR, forwarding is done by the node closest to the destination. Acknowledgements (ACKs) are used to identify candidates that receive packets and one node forwards the packet. The route is built dynamically and data packets are forwarded in batches. The source node includes in each packet a list of candidate forwarders prioritized by the shortest path to the destination. The candidates that received the packets are marked in the BITMAP option in each packet. The highest priority candidate then broadcasts the packets with the copy of its batch map. Batch map contains the node with the highest probability to have received the packet. The remaining forwarders then transmit in order of priority, but only send packets which were not acknowledged in the batch maps of higher priority nodes. ExOR performs better than traditional routing for almost all node pairs, incrementing the end-to-end throughput by a factor of two. ExOR uses ETX metric for prioritization of selected candidates and the ETX information is collected via periodic link-state flooding of control packets. ExOR has good routing performance but reduces spatial reuse because it enforces global coordination among forwarders. Also, candidates with low-quality links may be chosen since as ExOR considers only the shortest path to the destination.

MORE: MAC-Independent Opportunistic Routing and En-Coding: MORE uses network coding approach and avoids network coordination in opportunistic routing. Sender encodes the packets and forwards to the destination where they are de-coded. MORE reduces the spurious transmissions caused by broadcasting in opportunistic routing. This routing is scalable to large networks and ensures reliable packet delivery. MORE uses general linear codes for its network coding. The packets are forwarded as batches and only the packets of a same batch can be coded together. In MORE, data packets are always coded and carry a list of forwarders and a code vector [8, 9] recording how the native packets are combined. Receiver decodes only when all packets of the batch are received. Forwarders keep a TX counter calculated by a distributed algorithm based on ETX. Network coding is usually expensive and coding operations may cause CPU bottleneck at times. MORE provides better network coding by limiting the number of packets that can be coded together and by checking the independence in processing code vectors.

CodeOR: Opportunistic Routing in Wireless Networks with Segmented Network Coding: CodeOR utilizes network coding to increase unicast throughput in wireless networks [10]. It performs segmented network coding, where the data is partitioned into multiple segments and the packets in the same segment are encoded and forwards a window of multiple segments concurrently. It follows end-to-end data packets approach for forwarding data packets. CodeOR is especially appropriate for real-time multimedia applications through the use of a small segment size to decrease decoding delay. CodeOR does not drop packets thus avoiding segment losses in the network.

Soar: Simple Opportunistic Adaptive Routing: SOAR supports simultaneous flow in multiple paths. SOAR incorporates adaptive forwarding path selection to leverage path diversity while minimizing duplicate transmissions. It follows priority timer-based forwarding to let only the best forwarding node forward the packet and local loss recovery to efficiently detect and retransmit the lost packets. SOAR provides adaptive rate control to determine the appropriate rate to send packets according to the current network conditions. SOAR is a proactive link state routing protocol [11]. Nodes periodically measure and disseminate link quality in terms of ETX. Using this information, sender selects a default path and the list of nodes eligible for forwarding data to the next hop. It then broadcasts the data packets. SOAR adjusts sending rates according to network conditions and recovers lost packets using efficient local feedback and recovery.

To-Go: Topology Assisted Geo-Opportunistic Routing: TO-GO combine's topology assisted geographic routing with opportunistic forwarding. TO-GO uses road topology informa- tion for the forwarder set selection. It exploits the simultaneous packet receptions induced by the broadcast nature of wireless medium and performs opportunistic forwarding via a subset of the neighbours that have received the packet correctly. TO-GO avoids bad links and is robust to channel impairments. TO-GO uses an enhanced beacon to predict the target node that is either the node furthest from the sender or the junction node that can forward packets in any direction. A simple junction prediction algorithm [12] with topology information and enhanced beaconing is used and the candidate set is then adjusted to reduce duplicate transmissions.

CORMAN: Cooperative Opportunistic Routing in Mobile Adhoc Networks: CORMAN is designed to support multiple simultaneous data flows. When a node overhears a packet from a nearby node, it records the time that this happens to estimate how long it will take for the node to transmit all packets in the fragment. The overhearing node uses this estimate to decide when it should start transmitting its own fragment. This introduces the back-off time of the DATA frame in order to reflect the traffic load in the network. If multiple flows are competing for the network resources, CORMAN allows them to share the network in an orderly fashion. CORMAN facilitates opportunistic data forwarding using the link quality diversity at different receivers and allows them to cooperate with each other with a minimal overhead and thus it has a strong resilience to link quality fluctuation and node mobility. CORMAN is a network layer solution to the opportunistic data transfer [13] in mobile ad hoc networks and its coordination mechanism is based on ExOR. CORMAN uses proactive source routing to exchange network information.

CCACK: Efficient Network Coding Based Opportunistic Routing Through Cumulative Coded Acknowledgments: CCACK exploits a novel Cumulative Coded ACKnowledgment scheme that allows nodes to acknowledge network coded traffic to their upstream nodes in a simple way, oblivious to loss rates and with practically zero overhead. In addition, the cumulative coded acknowledgment scheme in CCACK enables an efficient credit-based, rate control algorithm. In this protocol in order to reduce redundant packets, cumulative coded acknowledgments (CCACK) utilize a null-space based (NSB) acknowledgement for network coding [14]. Relays add a hash (vector) in the packet header to disseminate its space information to others. When a relay overhears the hash from its neighbors, the relay can determine if it can generate linearly independent packets for its neighbors or it should stop sending.

EEOR: Energy-Efficient Opportunistic Routing: In this protocol, the forwarding list selected and prioritized to minimize the total energy cost of forwarding data to the sink node in a wireless sensor network (WSN). A subset of neighboring nodes is chosen as forwarder list of node u such that the expected cost for u to send a packet to the target is minimized. When at least one node in the forwarder list of node u received the packet successfully, we need to calculate the expected cost to forward the packet sent by node u. Here, we assume that only one node from the forwarder list that received the packet will forward the packet. Although this assumption is very optimistic, in most cases, it is true. The expected cost that is calculated here could be slightly lower than the actual cost when multiple nodes from forwarder list forward

Table 1: Classification and Opportunistic Routing Protocols

Opportunistic Routing	ExOR	MORE	CodeOR	SOAR	TO-GO	CORMAN
Candidate Selection	ETX	ETX	ETX	ETX	Distance	ETX
Location or Topology Based	Topology Based	Topology Based	Topology Based	Topology Based	Location,Topology Based	Topology Based
Forwarder selection	End-to-End	End-to-End	End-to-End	Hop-by-hop	End-to-End	End-to-End
Prioritization	Deterministic	Deterministic	Deterministic	Deterministic	Deterministic	Probabilistic

the data packet. the EEOR [15] protocol should be able to handle the network traffic efficiently, *i.e.*, be able to handle with congestion, to avoid bottleneck in order to decrease packet loss ratio and save the energy cost at the same time.

MSTOR: Minimum Steiner Tree with Opportunistic Routing: In MSTOR [16], the source and receivers are connected by an overlay Steiner tree. The source multicasts packets along the overlay links of the Steiner tree to reach all receivers. The transmission of packets on each overlay link is controlled by unicast OR. This routing propose an overlay construction algorithm based on the optimal ”OR distance” between nodes. The OR distance between nodes i and j is the expected total number of transmissions to send a packet from I to j using unicast OR. By allowing any pair of nodes in the network communicate with each other using unicast OR, we construct a fully connected overlay graph out of the underlying wireless network. In the overlay graph, the source node calculates a minimum overlay Steiner tree with OR distances as overlay link weights. The overlay Steiner tree acts as a virtual back- bone to deploy unicast OR from the source to receivers. The aggregate OR distance cost of the tree is the expected total number of OR transmissions to send one packet from the source to all receivers.

Efficiency of Opportuinistic Routing: In order to achieve high throughput in OR, it is important to choose an optimal candidate set that improves the efficiency of the network. The candidate set size deeply affects the routing performances in terms of overhead for candidate coordination. Candidate set size can be either fixed or variable. Most of the opportunistic routing protocols use ETX as routing metric to select forwarder list or assume the optimal forwarder list is pre-selected. Yanhua Li, Wei Chen and Zhi-Li Zhang used an event-based analytical methodology in for studying the forwarder list selection problem and to develop an optimal so-lution which minimizes the expected number of transmissions. Angela Sara Cacciapuoti, Marcello Caleffi and Luigi Paura proposed in [17] a constrained candidate set selection using a fixed maximum candidate set size. an effective opportunistic routing protocol has to implement a mechanism to single out, among all the neighbor nodes that have successfully received the packet, the one that maximize the routing progress of each data transmission toward the destination.

Given a transmitter node Si and a receiver Dj, the Candidate Forwarding Set (CFS) for Si to Dj is Fij = (Si1, Si2, Siq, Sir). For each relay node Siq that belongs to Fij, the transmission advancement diiq is the difference between the OR shortest distance from transmitter node Si to the receiver Dj and OR shortest distance from candidate relay node Siq to receiver Dj: diiq = LSiDj-LsiqDj (4) diiq represents the OR transmission advancement when a packet successfully transferred from transmitter node Si to relay node Siq toward receiver Dj.

Chun-Pong Luk, Wing-Cheong Lau and On-Ching Yue in [18] use uniformly distributed nodes on a 2D plane according to a spatial Poisson distribution with average number of nodes per unit area ë. Rmax is taken as the maximum transmission range of any node beyond which the probability of successful packet reception becomes very small and can therefore be neglected.

Best-path routing which is considered well-suited for wired networks with relatively stable point-to-point links may not be an ideal approach for wireless networks with lossy broadcast links. Best-path routing schemes trigger many packet retrans- missions or path rediscoveries since wireless transmissions tend to have high loss rates as they are susceptible to ex- ternal interference, multi-path fading and inclement weather. Moreover, wireless channel conditions vary at a fast time scale that the best path at an instant may not be good at the next instant. Recent research has highlighted the effectiveness of opportunistic routing schemes where, forwarding nodes can be selected dynamically for each packet and each hop, on the basis of the actual network performance which allows each packet to take advantage of the local pattern of transmissions at any time.

CONCLUSION

Opportunistic Routing presents a promising methodology to improve the performance of wireless adhoc, mesh, and sensor networks. Opportunistic Networks do not have existing routes and the path has to be found dynamically. This makes Opportunistic Routing a challenging area in infrastructure-less networks. Effectiveness of these protocols relies on the candidate selection and prioritization techniques and the coor-dination method used. Opportunistic Routing takes advantage of the broadcast nature of the wireless networks to increase transmission reliability.

Selecting the forwarding nodes and coordinating them helps reduce duplicated retransmissions and increase network throughput and thus provide improved performance in wireless networks. Forwarding nodes can be selected dynamically for each packet and each hop, on the basis of the actual network performance. The Various Opportunistic Routing protocols and metrics used in them were discussed. And the efficiency of these protocols based on the different candidate selection algorithm and coordination method were analysed.

REFERENCES

1. Biswas, S. and R. Morris, 2005. ExOR: opportunistic multi-hop routing for wireless networks, in: Proceedings of SIGCOMM, ACM, Philadelphia, Pennsyl-vania, USA, pp: 133-144.
2. Hsu, C.J. and H.I. Liu, 2009. W. Seah, Economy: a duplicate free opportunistic routing, in: Proceedings of the 6th International Conference on Mobile Technology, Application and Systems, ACM, Nice, France, pp: 16.
3. Ahlswede, R., C. Ning, S.Y.R. Li and R.W. Yeung, 2000. Network information flow, IEEE Transactions on Information Theory, 46: 1204-1216.
4. Couto, D.S.J.D., D. Aguayo, J. Bicket and R. Morris, 2003. A high-throughput path metric for multi-hop wireless routing, in: Proceedings of the 9th Annual International Conference on Mobile Computing and Networking (MobiCom), ACM, San Diego, CA, USA, pp: 134-146.
5. Sumathy, S. and Dr. R. Saravanan, 2011. ETX Metric for Extremely Opportunistic Routing to improve the performance of Hybrid wireless networks, Inter-national Journal of Ad hoc, Sensor and Ubiquitous Computing (IJASUC), pp: 2.
6. Draves, R., J. Padhye, B. Zill, 2004. Routing in multi-radio, multi-hop wire-less mesh networks, in: Proceedings of the 10th Annual International Conference on Mobile Computing and Networking (MobiCom), ACM, Philadelphia, PA, USA, pp: 114-128.
7. Zhong, Z. and S. Nelakuditit, 2007. On the efficacy of opportunistic routing, in: Proceedings of the 4th Annual IEEE Communications Society Conference on Sensor, Mesh and Ad Hoc Communications and Networks (SECON), San Diego, CA, USA, pp: 441-450.
8. Chachulski, S., M. Jennings, S. Katti and D. Katabi, 2007. Trading structure for randomness in wireless opportunistic routing, in: Proceeedings of SIGCOMM, ACM, Kyoto, Japan, pp: 169-180.
9. Szymon Chachulski, Michael Jennings, Sachin Katti and Dina Katabi, 2006. MORE: A Network Coding Approach to Opportunistic Routing, MIT-CSAIL-TR-2006-049.
10. Lin, Y., B. Li and B. Liang, 2008. CodeOR: Opportunistic routing in wireless mesh networks with segmented network coding, in: Proceedings of the IEEE International Conference on Network Protocols (ICNP), Orlando, FL, USA, pp: 13-22.
11. Rozner, E., J. Seshadri, Y.A. Mehta and L. Qiu, 2009. SOAR: simple opportunistic adaptive routing protocol for wireless mesh networks, IEEE Transactions on Mobile Computing, 8: 1622-1635.
12. Lee Kevin, C., Uichin Lee and Mario Gerla, 2010. Geo-Opportunistic Routing for Vehicular Networks, Communications Magazine, IEEE.
13. Wang Zehua, Yuanzhu Chen and Cheng Li. CORMAN: A Novel Cooperative Opportunistic Routing Scheme in Mobile Ad Hoc Networks, IEEE Journal on selected areas of Communications, 30(2).
14. Koutsonikolas, D., C.C. Wang and Y.C. Hu, 2012. CCACK: efficient network coding based opportunistic routing through cumulative coded acknowl- edgments, in: Proceedings of the IEEE Conference on Computer Com- munications (INFOCOM), San Diego, CA, USA, pp: 19.
15. Xufei, Mao, Shaojie Tang, Xiaohua Xu, Xiang-Yang Li and Huadong Ma, 2011. Energy-Efficient Opportunistic Routing in Wireless Sensor Networks, IEEE Transactions on Parallel and Distributed systems, 22: 11.
16. Tan, Le, Yong Liu, Opportunistic Overlay Multicast in Wireless Networks, Global Telecommunications Conference (GLOBECOM 2010), 2010 IEEE.
17. Angela Sara Cacciapuoti, Marcello Calef and Luigi Paura, 2010. Optimal Con-strained Candidate Selection for Opportunistic Routing, Global Telecommunications Conference (GLOBECOM 2010), IEEE.
18. Chun-Pong Luk, Wing-Cheong Lau and On-Ching Yue, 2008. Analysis of Opportunistic Routing in Wireless Mesh Network, IEEE Communications.