International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 13 (2017) pp. 3822-3827
 https://dx.doi.org/10.37622/IJAER/12.13.2017.3822-3827

Conservative Spatial Reuse Routing in Multi-Hop Cognitive Sensor Networks

K L Arun Kumar[1], Dr. P V Nageswara Rao[2]
[1,2]Department of Computer Science and Engineering, GITAM Institute of Technology, GITAM University, Visakhapatnam, India.

Arjun Atreya V[3]
Root 2 Research Labs, Bengaluru, Karnataka, India.

[1]Orcid: 0000-0002-5131-9404, [2]Orcid: 0000-0002-0281-2323, [3]Orcid: 0000-0002-0120-3593

Abstract

Wireless Networks have been part of our daily life in the last decade or so. The advances in wireless networks helped it to sustain, enrich and adapt to multiple applications which a human interacts. In last decade, researchers have specifically shown lots of interest in the area of mobile ad-hoc and sensor networks. This paper proposes a practical solution for spatial reuse routing in wireless sensor networks. There has been many research papers that address the concept of spatial reuse, but very few discuss the spatial reuse for routing. The disadvantage with most of these research works is that the complexity of finding the spatially reusable links. In this paper, we propose a *conservative* approach for spatial reuse which reduces the complexity of finding spatially reusable links. This approach is called conservative because we carefully choose the spatially reusable links in the routing path and sometimes this choice may not be optimal. However, the overhead that we incur is because of the reduction in the complexity of finding spatially reusable links in the routing path. The experimental results show that the conservative spatial reuse routing performs comparable to that of spatial reuse routing with the reduction in the complexity of finding the routing path. We validate our claims through both analysis and simulations.

Keywords: Spatial Reuse, Multi-Hop Routing, Conservative Approach

INTRODUCTION

The advanced research in Wireless Communication has made feasible low power, low cost, multifunctional sensors. WSN is a special type of Ad-Hoc network with randomly deployed nodes assigned with the task of monitoring the surveillance area.

The wireless feature of WSN adds to several advantages over wired networks, such as saving wiring costs and allowing unlimited reconfiguration and customization in future. The sensor network is specialized by the following features: (i) Sensor node is equipped with an additional processing and sensing component. (ii) It can perform tasks of sensing and communication simultaneously. (iii) Sensor nodes mainly use broadcast communication. (iv) The control of WSN through a base station enables monitoring regions where human intervention is not possible.

Wireless Sensor Network is a collection of sensor nodes in which each node has RF Transceiver, Processing Unit, and power Source apart from sensing and actuating units with battery power and spectrum availability constraints. These constraints can be exploited by incorporating Cognitive capability to the WSN.

Cognitive Wireless Sensor Networks are the networks with cognitive ability with which the nodes in the network can learn from its surroundings and change its communication parameters according to the changes in its surroundings. Unlike traditional Wireless Networks, Cognitive Network (CN) provides efficient spectrum utilization and enables opportunistic access to the spectrum. The nodes in cognitive wireless sensor networks changes transmission and reception parameters according to the radio environment, improves spectrum utilization and increases communication quality.

WSN consists of sensor nodes and a base station [1]. A Battery, sensor to detect an physical event in the environment within the stipulated range called *sensing range* and an antenna (omni-directional or unidirectional) is embedded in a sensor node. *Base station* or a *Sink* is a controller node that gives commands to the network and receives data from the network.

In WSN, like in any other wireless networks multi-hop routing is a need and in turn decides the performance of the network. As in any other multi-hop routing network, the challenge of choosing the *best* path is essential. With the link quality metrics like ETT, ETX, RTT etc., the challenge is to find the best and the optimal (in terms of link quality) path for routing data between two nodes in the network. In this paper, we establish the conservative approach in identifying the optimal path between the source and destination considering the spatial reuse of channel between the neighboring nodes.

Cognitive Networks are comprised of a set of self-aware, self-reconfigurable nodes with cognitive capabilities. These networks are different from traditional Wireless Sensor Networks. Providing cognitive capability to the sensor nodes enables Dynamic Spectrum Access (DSA), reduces power consumption and reduces network traffic by effective utilization of the spectrum. The DSA allows the users to access the unused spectrum dynamically.

Incorporating cognitive capabilities to the WSN brings out many benefits such as improved spectrum sensing, improved coverage, reduced power consumption without sacrificing network performance, higher data rate, less power consumption, low delay, better data reliability, Communication Quality *etc*. Cognitive Wireless Sensor Networks can be used in different applications such as military, agriculture, habitat monitoring, nuclear reactor control, security and tactical surveillance, object tracking, medicine and health, logistics, Transportation and Vehicular Networks etc.

QoS is an idea where the network capacity, transmission rate, error rate, accuracy, delay, throughput and other Quality of Service metrics can be measured and improved in a network by incorporating certain algorithms. It is the ability to guarantee to a certain level of performance in a network. Spatial Re-usability in Wireless Networks has become a key point to improve network capacity. It is an important property of Wireless Networks which allows to use the same spectral link at the same time and send packets simultaneously if the links are in non interference range. By considering this property the end to end throughput in multihop wireless networks can be improved considerably.

The rest of the paper is organized as follows: Section II discusses the literature related to the proposed routing algorithm. Section III details the theory of interference and spatial reusability of channel in routing. Our approach is discussed in section IV. The experiments and results are presented in section V and we conclude in section VI.

RELATED WORK

In this section, we briefly review literature in the area of wireless routing protocols and spatial reusability. The earliest single-path routing protocols in [1], [2] used Dijkstra algorithm for route selection. For anypath routing ExOR [3] was proposed to be coordination between forwarders; [4] proposed the shortest anypath first (SAF) algorithm to determine the forwarders' priority; CodeOR [5] enabled concurrent transmissions using window; SourceSync [6] utilized diversity at the sender. Transmission cost was the predominant routing metric that was used to design these routing protocols, guarantee of maximum throughput using spatial reusability was lacking.

Some existing approaches consider routing and scheduling wireless link (e.g., [7],[8]) for cost minimization. Although in theory these research articles can provide considerable performance, they need centralized controller to realize MAC-layer scheduling. The proposed algorithm do not require any scheduling and has less overhead. Also, there exist works aimed at exploiting spatial reusability [9], [10], [11], [12], [13], [14]. Specifically, [7] details the effect of carrier sense range for spatial reuse in wireless networks. But, none of these works deal with the problem of route selection. The latest work and the only work that deal with spatial reuse routing is [15], However, the computational overhead in this work is so high on destination nodes that makes it impractical for energy constrained wireless networks which is the case in sensor networks.

INTERFERENCE AND SPATIAL REUSE

In this section, we discuss the effect of interference on routing and how spatial reusability of channel that helps in increasing the throughput. The best example or an illustration of interference could be seen in a classic hidden node problem. Figure 1 shows the scenario of hidden node problem, where node *A* is transmitting a data to node *B* in a particular channel and hence node *C* cannot use the same channel for data transfer. In the case unidirectional routing, we extend the hidden node problem to illustrate the spatial reuse in a routing path as shown in figure 2, where node *A* is communicating to *B* and node *D* is communicating to node *E* in the same channel. In an ideal scenario, this is possible because the node pair *AB* and *DE* are independent of each other. This theory of channel reuse fails if node *D* is in communication range of node *A*, even though node *A* is not transmitting data with node *D* directly. Hence it is important that node *D* must not be a neighbor to node *A* for the channel reuse to happen among the node pairs *AB* and *DE*. The constraint applied to node *D* also applies to node *E* for reusing the channel while data transfer. We define *exclusive neighbors* of a node *X* as all the nodes that are in the communication range of node *X* and not limited to the neighbor node which is part of the routing path. In comparison to the existing distance vector routing algorithms that maintains routing table, we maintain the list of all neighbors instead of only those neighbors that are part of established routing paths.

A. Challenges for Spatial Reuse

Apart from the problem of interference there are several challenges that has restricted the practical implementation of spatial reuse in multi-hop wireless networks. To the best of our knowledge [15] is the only work that talks about the usage of spatial reuse in routing of wireless networks. However even in that work, we see an overhead on all the destination nodes to actually estimate the spatial reuse links with every routing path discovered. There is a packet overhead as well as the computational/processing overhead on destination node that makes it difficult to adapt in WSN. The complexity involved is in the order of $O(N^3)$. [15] provides an approximation algorithm to reduce the complexity but however fails to evaluate the impact of processing power on the nodes for spatial reuse calculation.

We look at the spatial reuse as a straight forward graph coloring problem where two adjacent links cannot have the same color. The idea is to choose a set of links in a routing path that do not have an overlapping communication ranges of associated nodes. With every node knowing its neighbors, we aim to achieve the spatial reuse by indicating exclusiveness of a node pair from other pairs. This is explained in detail in the next section.

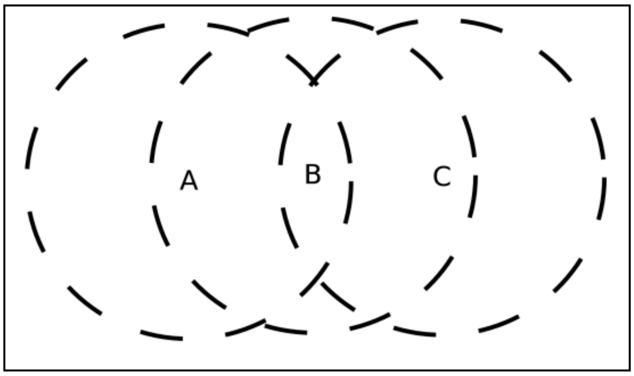

Figure 1: Hidden node problem

OUR APPROACH

We call our approach as conservative spatial reuse routing (CSRR) in our discussions and experiments. The CSRR is not an independent routing algorithm in itself. It complements any routing protocol that is used in the network to enable the spatial reuse with minimal overhead. The main classification of routing algorithms in wireless networks is (a) link state routing and (b) distance vector routing. Our approach complements routing algorithms that fall in both these algorithms. However, the overhead varies based on the routing algorithm with which the CSRR approach is used. The idea in our approach is to store adjacent node pair information so that alternate node pairs could be assigned with the same channel for transmission.

For effective illustration, we consider DSR algorithm with CSRR for routing. For every routing path discovered in the network, the source node sends a data packet that needs to be forwarded by specific set of nodes in the routing path till the destination receives the packet. Every node after receiving a packet does the following operations before fulfilling its duty (forwarding/discarding).

- Checks if the node that sent this packet and a node to which it needs to forward the packet are neighbors. In other terms a node receiving a packet checks if previous node and the next node are not exclusive neighbors.
- If the afore mentioned condition is satisfied then the node forwards the packet saying the following node pair (link between the next node and the following node after the next node) is a potential spatial reusable link that the current node pair (link between the current node and previous node) is using.
- The next node after receiving a packet see a indication from previous node about the link being spatially reusable, checks if its next node and previous node are exclusive neighbors or not. if not, it aserts the link to be spatially reusable with the first link.

Let us illustrate with a toy example as shown in the figure 3. Note that the node *A* has a neighbor node *B*. Node B has two neighbors node *C* and node *D* which in turn has a neighbor node *E*.

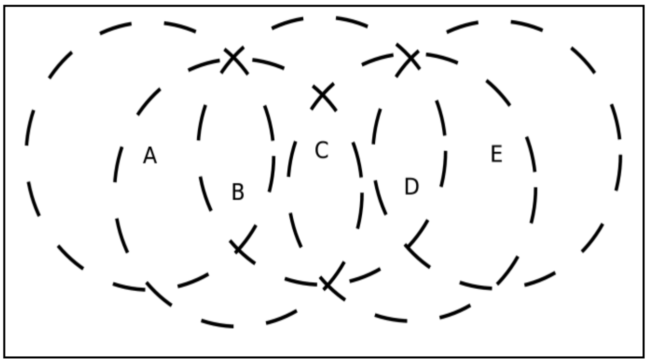

Figure 2: Spatial Reuse in a routing path

From there it is a linear topology between node *E*, node *F* and node *G*. Our algorithm demands the neighbor information to be stored for two levels. In other words every node has an information about its neighbors and their neighbors in turn. We may use any routing algorithm (lets say for instance DSR) to find a route between node *A* and node *G*.

The path chosen could be either *A-B-C-E-F-G* or *A-B-D-E-F-G*. The DSR would then start transmitting the data traffic between node *A* and node *G*. Our CSRR aims to find the pairs in these routing paths *i.e.,* {*A-B,E-F*} and {*B-C/D,F-G*} are spatially reusable pairs. Node *C* when it receives a packet identifies that node *B* and node *E* are

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 13 (2017) pp. 3822-3827
© Research India Publications. https://dx.doi.org/10.37622/IJAER/12.13.2017.3822-3827

not exclusive neighbors and hence append the packet with the information that link coming to node *B* and link from node *E* are spatially reusable. Node *E* after receiving this packet asserts again that node *C* and node *F* are not exclusive neighbors and hence accepts the spatial reuse information sent be node *C* as well as adds the potential spatial reuse information about link coming to node *C* and a link from node *F* and forwards the packet.

The CSRR approach is called a *conservative approach* because of the following reasons.

- We do not try identifying the optimal number of spatial reusable links in the routing path. In case if we aim to achieve optimality then every node need to have a complete routing path information and their neighbor information which is not viable.

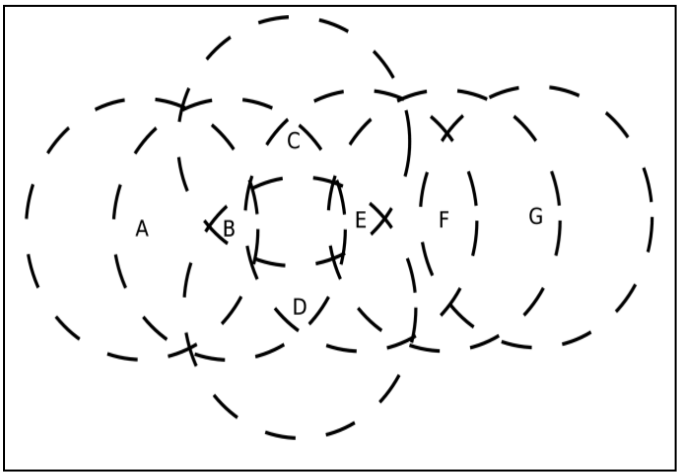

Figure 3: Toy example illustrating CSSR

- We apply greedy technique in finding the spatially reusable links *i.e.,* we aim to find the earliest link in the routing path that is reusable with the first link of the path. We progressively try to find it this way to achieve spatial re-usabilty which may not be optimal.

EXPERIMENTS AND RESULTS

We run our experiments using NS2 and compare our implementation with the DSR and OLSR routing algorithms. The idea is to evaluate the effect of CSRR on DSR and OLSR algorithms to evaluate the throughput of the system. The generated traffic is CBR between multiple node pairs during simulation. We try evaluating the end-to-end throughput between the nodes to see the benefits of CSRR algorithm. The implementation details are in table I.

Table I. Implementation details

Parameter	Value
Routing Protocol	DSR, OLSR
Network Area	670X670
Number of Nodes	50
Transmission Rate	5 Mbps, 11 Mbps
Traffic Generator	CBR
CBR Rate	4 pkts/sec
Packet Size	512 Bytes

We present detailed pairwise throughput comparisons in figure 4 and 5 for DSR and OLSR respectively. All the 100 simulated node pairs are sorted by their throughputs under DSR and DSR-CSRR in a non decreasing order. Similarly the throughputs for OLSR and OLSR-CSRR as well. We observe that DSR-CSRR shows clear throughput improvements, especially when DSR does not perform well. Except for some node pairs, we see more than 15% node pairs have doubled throughputs, and the throughput gain achieved by DSR-CSRR reach □ 2.5x better performance than the DSR algorithms.

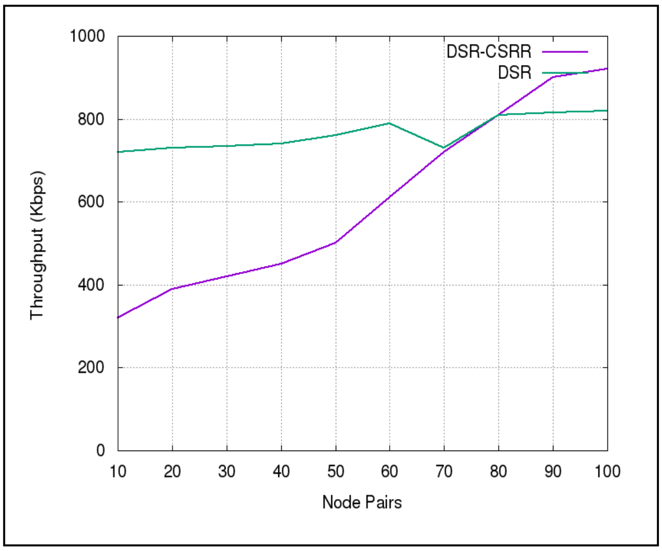

Figure 4: End-to-end throughput for DSR

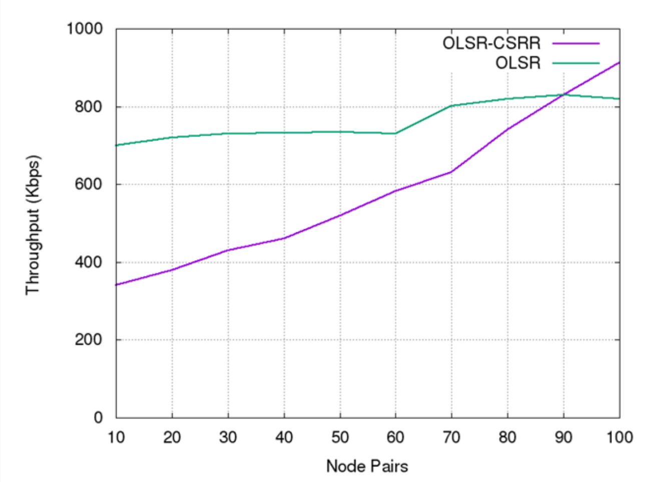

Figure 5: End-to-end throughput for OLSR

We observe similar results for OLSR as well. The results of SASR algorithm in [15] is much better than the DSR-CSRR.However, as discussed earlier, SASR algorithm has more overhead on the nodes compared to that of DSR-CSRR/OLSR-CSRR. It can be noted that the throughput gains are evident for those node pairs which perform bad in DSR, because these pairs have larger hop counts providing ample opportunities for spatial reusability.

We also see the effect of our algorithm with varying hop counts. We fix the number of node pairs as 50 with a specific hop count and run the simulations to record the throughput as shown in figures 6 and 7 for transmission rates of 1Mbps and 5Mbps respectively. We observe that the throughput is same when hop count is 1, 2 and 3 as there is no chance of spatial reuse in such cases. However, as the hop count increases the throughput of DSR-CSRR increases as compared to DSR for varying transmission rates. This improvement is monotonically increasing as the hop count increases.

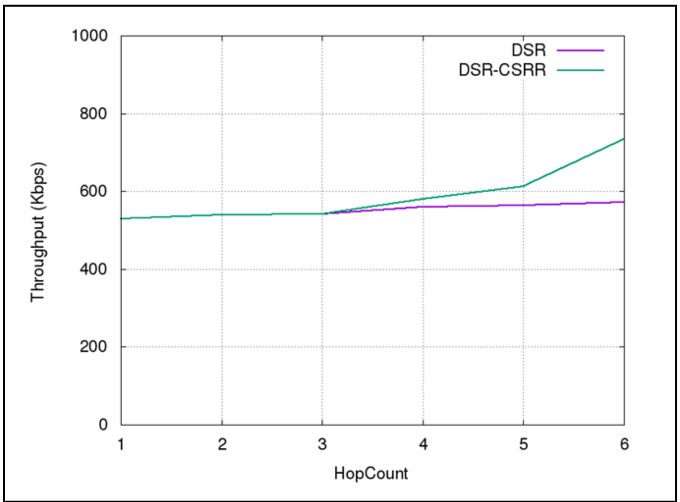

Figure 6: Throughput for varying hop count for transmission rate of 1 Mbps

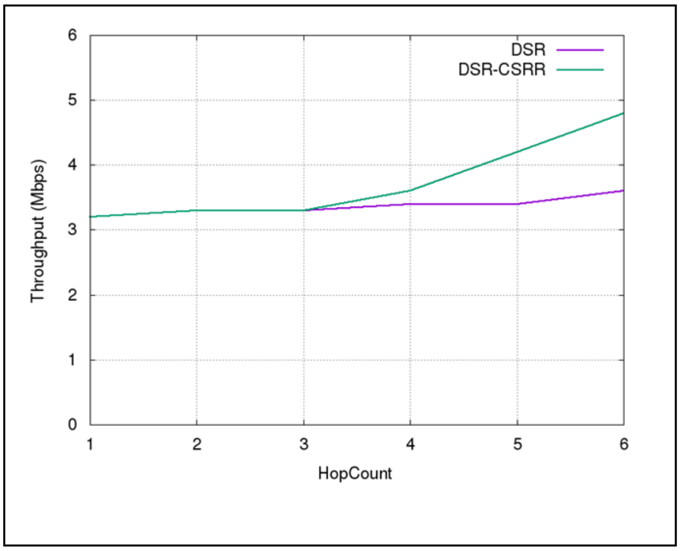

Figure 7: Throughput for varying hop count for transmission rate of 5 Mbps

CONCLUSIONS

In this work, we propose a conservative spatial reuse routing (CSRR) for utilizing the link resources to enhance the end-to-end throughput of the wireless network. The CSRR could be used with any routing algorithm (both linkstate and distance vector) to enhance the performance throughput using spatial reuse of transmission channel. We experimented our CSRR algorithm with DSR and OLSR routing in NS2 and the performance show an consistent improvement of ~2.5x. that of the vanilla DSR and OLSR. The performance of CSRR however depends on the routing path length like any other spatial reuse routing. Higher the routing path length, higher the chance of spatial reuse. We claim that our CSRR algorithm has a least overhead and hence make it practically usable for multi-hop wireless sensor networks.

REFERENCES

[1] D.B. Johnson, D.A. Maltz, in Mobile computing (Springer, 1996), pp. 153–181.

[2] C.E. Perkins, P. Bhagwat, in ACM SIGCOMM computer communication review, vol. 24 (ACM, 1994), vol. 24, pp. 234–244.

[3] S. Biswas, R. Morris, in ACM SIGCOMM Computer Communication

[4] Review, vol. 35 (ACM, 2005), vol. 35, pp. 133–144.

[5] R. Laufer, H. Dubois-Ferriere, L. Kleinrock, in INFOCOM 2009, IEEE (IEEE, 2009), pp. 37–45.

[6] Y. Lin, B. Li, B. Liang, in Network Protocols, 2008. ICNP 2008. IEEE International Conference on (IEEE, 2008), pp. 13–22.

[7] H. Rahul, H. Hassanieh, D. Katabi, ACM

SIGCOMM Computer

[8] Communication Review 41(4), 171 (2011).

[9] N.M. Jones, B. Shrader, E. Modiano, in INFOCOM, 2012 Proceedings

[10] IEEE (IEEE, 2012), pp. 352–360.

[11] M. Pan, C. Zhang, P. Li, Y. Fang, in INFOCOM, 2011 Proceedings

[12] IEEE (IEEE, 2011), pp. 2237–2245.

[13] T.S. Kim, H. Lim, J.C. Hou, in Proceedings of the 12th annual international conference on Mobile computing and networking ((ACM, 2006), pp. 366–377.

[14] H. Zhai, Y. Fang, et al., in INFOCOM, vol. 6 (2006), vol. 6, pp. 1–12.

[15] A. Kessleman, G. Li. Techniques for spatial reuse in wireless personal area networks based on virtual time divisional multiple access (2015). US Patent 9,008,058.

[16] M.A. Javed, D.T. Ngo, J.Y. Khan, Vehicular Communications 2(1), 27 (2015).

[17] W. Feng, Y. Niu, Y. Li, B. Gao, L. Su, D. Jin, D.O. Wu, IET Communications 10(4), 425 (2016).

[18] T. Meng, F. Wu, G. Chen, A.V. Vasilakos, in Global Communications Conference (GLOBECOM), 2014 IEEE (IEEE, 2014), pp. 88–93

[19] T. Meng, F. Wu, Z. Yang, G. Chen, A.V. Vasilakos, IEEE Transactions on Computers 65(1), 244 (2016). DOI 10.1109/TC.2015.2417543.