Poster – SEA-OR: Spectrum and Energy Aware Opportunistic Routing for Self-Powered Wireless Sensor Networks

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ABSTRACT

An appealing solution for unattended surveillance and monitoring applications is Self-powered Wireless Sensor Networks (WSNs). One of the main reasons is that the energy which is derived from power harvesting can significantly extend the network lifetime. Consequently, the network can work unattended for long periods. However, WSNs are characterized by multi-hop lossy links and resource constrained nodes while they have to face the coexistence problem with other applications. Opportunistic Routing (OR) is a routing paradigm to improve network performance in lossy wireless networks. At the same time, Cognitive Radio (CR) technology enables unlicensed operation in licensed bands. In this work, a combination of these two research approaches in a novel routing protocol is presented. A Spectrum and Energy Aware Opportunistic Routing (SEA-OR) protocol is proposed and designed for Self-powered WSNs. Moreover, a prioritization scheme which balances the packet advancement, the residual energy and the link reliability is introduced. Preliminary results show an improvement in network lifetime and delivery ratio. The performance of the introduced protocol is also evaluated in prototypes.

Categories and Subject Descriptors

C.2.1 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Architecture and Design—*Wireless communication*; C.2.2 [**COMPUTER-COMMUNICATION NETWORKS**]: Network Protocols—*Routing protocols*

Keywords

Cognitive radio networks; Cognitive routing protocols; Self-powered wireless sensor networks

1. INTRODUCTION

Wireless Sensor Networks (WSNs) hold great promise as an enabling technology for a variety of applications, including event monitoring and tracking. A principal reason is that low cost inch scale sensors can be designed to work unattended for long periods of time. However, survivability is a looming threat for WSNs and their successful deployment. The network lifetime is solely decided by how the limited energy of each node is utilized. In addition, the devices that use the unlicensed bands increase every day hence, there is an increased demand on efficient spectrum utilization.

Opportunistic Routing (OR) [1] along with cognitive networking principles can alleviate these problems. The dynamic aspect of OR offers a set of candidate paths to the destination while cognitive radio quickly adapts to the dynamic spectrum conditions [3]. Hence, self-powered and cognitive enable WSNs can prolong network lifetime. Moreover, their deployment would have the least impact on the current infrastructures. The protocol that would be applied in these networks should be carefully designed and follow the network restrictions. Self-powered nodes have limited computational and storage capabilities while the spectrum sensing should carefully use the limited energy sources.

In this work, a Spectrum and Energy Aware Opportunistic Routing (SEA-OR) protocol for Self-powered WSNs is introduced. Moreover, a novel metric to prioritize the neighbour nodes is proposed. The new metric balances the packet advancement, the residual energy and the link reliability. SEA-OR achieves to extend network lifetime while it retains a high delivery ratio. The protocol is simulated and compared with Geographic Opportunistic Routing (GeOR) similar to [5]. Finally, SEA-OR has been applied to prototypes at our Self-Powered Sensor Network (SPSN) testbed.

2. SYSTEM ARCHITECTURE

The introduced SEA-OR protocol was developed for our second generation Cognitive Radio Network (CRN) testbed architecture. The protocol was designed for an outdoor monitoring system for gas leak detection. The system has three important components: the **sensor units**, the **relay nodes** and the **control unit**.

Each **sensor unit** has a gas sensor connected with the radio board. The radio board has two antennas to perform the cognitive networking: one for channel sensing and one for packet transmission. The board is connected with a rechargeable battery which draws energy from a solar panel. During the daylight, when the rechargeable battery is fully charged, the board draws energy straight from the solar panel. When there is no sufficient sunlight for the panel, the board draws energy from the battery. The sensor unit

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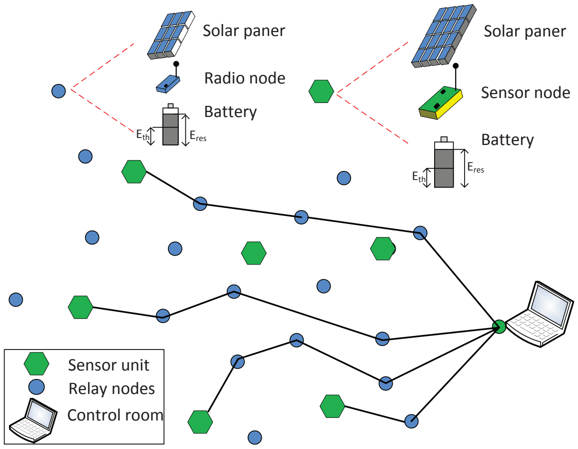


Figure 1: An outdoor gas leak detection system consists of self-powered units. The units have a threshold (E_{th}) in their batteries. If the battery level is below the threshold, they stop participate in any transmission and focus on energy harvesting.

forwards all the crucial information to the relay nodes over wireless communication, following the SEA-OR protocol.

The **relay nodes** have the same radio board with the sensor units. They forward all the packets towards the control room. Since there is no sensor attached to the board, the energy consumption at the relay nodes is significantly smaller in comparison with the energy consumption at the sensor units. Hence, the solar panel and the battery capacity at the relay nodes are smaller.

The **control room** is a radio board connected to a computer. This is the destination of all the packets. The radio board decomposes all the packets and displays the information on the GUI that have been developed.

Figure 1 depicts the outdoor system and its main components. Whenever there is a gas leakage in the monitoring area, the sensor units which are close, transmit packets with information regarding the leakage. The packets reach the control room and the system administrator is notified. A monitoring system like that poses a number of challenges:

Challenge 1: Network lifetime. Take Fig.1 for example. If the sensor units forward all the packets over the same relay nodes, these nodes will run out of energy after a number of transmissions. In this case, there will not be network connectivity which is a great threat for monitoring systems. Even though the nodes are powered with solar panels, they will acquire extra time to recharge their batteries to a level that they can participate in packet transmission again.

Challenge 2: Location information. There are many geographical routing protocols in the literature that can optimize the network performance. Usually, they use the distance between the communicate nodes as prioritization metric. The more accurate this information, the better the performance of the metric. However, in networks with high density and without advanced location estimation technologies, this metric might not be easily used. On the other hand, if advanced location systems are used, the cost and the power consumption per unit will increase.

Challenge 3: Wireless network coexistence. Heterogeneity and coexistence are characteristics of every unlicensed band. As more and more wireless devices use the 2.4 GHz radio spectrum, the coexistence of 2.4 GHz wireless devices which operate at the same place has become a challenging topic. The system should be able to cope with issues such as spectrum availability detection, interference mitigation and spectrum sharing.

Challenge 4: Dynamic changes. The monitoring system is deployed and should work unattended for long periods of time. Hence, it needs mechanisms to adopt successfully to a rapidly changing environment. For instance, the link between nodes might not be available due to obstacles from the environment. The system should be able to deliver the necessary packets to the destination on time.

To cope with these challenges, SEA-OR is proposed.

3. SEA-OR DESIGN

Central to the design of SEA-OR is a novel neighbour prioritization metric for Self-powered WSNs.

SEA-OR Overview. SEA-OR discovers multiple paths towards the destination according to the spectrum dynamics as well as node availability and energy level in the node. The paths are centred around the shortest path. The protocol opportunistically expands or shrinks these paths, based on the spectrum availability and the residual energy of the neighbour nodes. The discovery and coordination of the forwarder set follows the RTS/CTS handshake approach. The transmitter senses for an available channel and broadcasts a RTS packet. SEA-OR opportunistically forwards packets across the links with the highest spectrum availability. The candidate node that replies first with a CTS packet, becomes the next relay node.

The novelty of SEA-OR protocol is on the prioritization mechanism. When a candidate node receives a RTS packet, it waits for a backoff time $T_{backoff}$ before it replies with a CTS packet. This time is designed for self-powered sensor nodes with limited computational capabilities. The nodes are prioritized based on a combination of the channel quality, the distance and the residual energy in the node. The formula to calculate the $T_{backoff}$ is as follows:

$$T_{backoff} = C_1 \times (E_{th} - E_{res}) \times \log(\frac{RSSI(d)}{A})) + SIFS \quad (1)$$

where C_1 is a constant related with the capacity of the battery, E_{th} is the threshold below which a node stops transmitting, E_{res} is the percentage of the residual energy in the node, d is the distance from the sender and A is the RSSI at one meter of distance. The $T_{backoff}$ can be seen in Fig. 1.

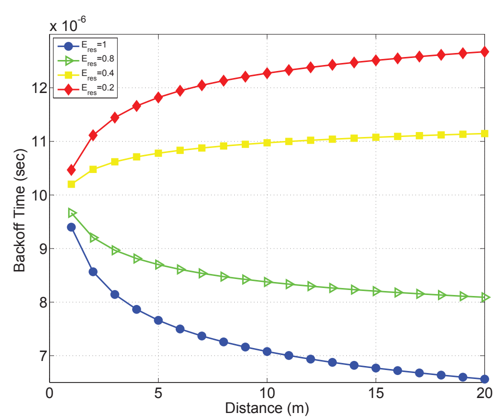


Figure 2: The $T_{backoff}$ for nodes in different distances from the transmitter and for different E_{res}, following Eq.1 for $E_{th} = 0.55$, $C_1 = 10^5$ and A = -40.

From Eq.1, the two important factors are the residual energy and the RSSI. The first can be acquired with a simple circuit on the sensor units and the relay nodes. The RSSI value can be found on every packet captured from the node. Also, it can be used to calculate the distance between nodes but it is not of high accuracy. It is however, accurate enough to prioritize the nodes based on their location and link quality. The constant values for these examples are the values used in our testbed and are related with the prototypes we developed [4]. When the nodes have similar E_{res}, SEA-OR tends to use nodes which are in greater distance and hence, closer to the destination. However, as the E_{res} decreases, the protocol uses nodes that are closer to the transmitter. In this way, the nodes have sufficient time to perform power harvesting and not run out of energy.

SEA-OR addresses the four challenges as mentioned above.

Extend network lifetime. SEA-OR uses the residual energy of the nodes for prioritization of the forwarder set. The nodes participate in packet transmission according to their remaining energy. When the E_{res} is under E_{th}, the node does not participate in any transmission. This mechanism is adopted to avoid nodes from running out of energy.

When a node has low energy, the probability of receiving a packet is low. As the node increases the energy levels through the energy harvesting phase, it increases its probability of becoming a relay node for a packet transmission.

Use of RSSI. In this approach, RSSI is used as an indicator of the relative location of the nodes. SEA-OR uses this information and not the exact location. The indicator is used to find nodes close to the transmitter. Most important for system implementation, RSSI information does not add any extra overhead. RSSI can also be used as link quality indicator. As an example, if the RSSI value is below a threshold, the node knows that the channel is idle.

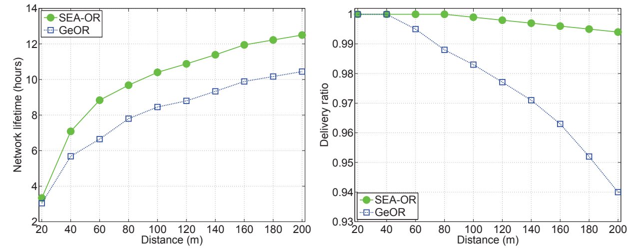
Opportunistic spectrum access. Before every packet transmission, the sender senses for the best available channel. The packet transmission takes place over the link with the highest spectrum availability at the time of the transmission. This approach also decreases the interference with other devices that use the same band and alleviates the problem of network coexistence.

Opportunistic routing. The SEA-OR protocol discovers paths towards the destination on demand. There is no predefined routing. For every packet transmission, the best available path is selected. This path is base on the network conditions at the transmission time. Any dynamic changes, like node and link availability, will change the best path. SEA-OR adapts to these changes quick and does not require any reconfiguration on the nodes.

4. EVALUATION

A preliminary evaluation of SEA-OR performance was conducted. The sensor nodes are randomly deployed in a 100×100 m^2 area using a Poisson distribution with a $\lambda = 0.101$. Every node has on average 8 neighbour nodes and the transmission range of each node is 12 m. The protocol was compared with GeOR.

Ten topologies were evaluated. The number of nodes in each topology varies between 900 to 1100. The distance between the source and the destination was varied between 20 to 200 meters. For each topology the source generated 1000 packets towards the destination. In every topology, 10 different source-destination pairs were selected.



(a) Network lifetime (b) Delivery ratio

Figure 3: Performance comparison between SEA-OR and GeOR in different source-destination distances.

Network lifetime. Network lifetime has plenty of definitions [2], depending on the application. In this work, and for a monitoring application, network lifetime is considered as the time until “connectivity” or “coverage” is lost, i.e. there are no paths between the source and the destination or one of the nodes runs out of energy. The network lifetime of the two protocols is shown in Fig. 3(a).

SEA-OR significantly improves network lifetime over GeOR. As the distance between the source and the destination increases, there are more nodes in the routing path. The spectrum awareness of SEA-OR forwards the packets in shorter time than GeOR. As a consequence, the nodes have to remain active for a shorter time and the energy consumption per node is smaller.

Delivery ratio.SEA-OR improves the delivery ratio of GeOR, as shown in Fig.3(b). The use of RSSI in the prioritization metric, helps SEA-OR decrease collisions and forward the packets over reliable links. Consequently, the number of retransmissions decreases.

5. CONCLUSIONS

In this work SEA-OR is introduced, a Spectrum and Energy Aware Opportunistic Routing protocol for Self-powered WSN. SEA-OR uses a novel prioritization metric to balance residual energy and packet advancement. The protocol was also compared with GeOR. It increases network lifetime while it keeps high delivery ratio. Also, the protocol has been implemented in prototypes in the SPSN testbed. Future work includes comparison of SEA-OR with other approaches over the testbed.

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