A Review of Relay based Underground Magnetic Induction Communication using Min-Max Approach

Mariam Ishtiaq
Division of Electronics and Electrical Engineering
Dongguk University
Seoul, South Korea
mariam.ishtiaq@gmail.com

Seung-Hoon Hwang*
Division of Electronics and Electrical Engineering
Dongguk University
Seoul, South Korea
shwang@dongguk.edu*

Abstract—Magnetic Induction (MI) communication using relays offers a promising solution to counter a number of inherent limitations of a Wireless Underground Sensor Network (WUSN) like energy constraint, deployment issues and limited communication range. In this paper, we give an extensive insight into developing an MI-WUSN that solves these issues by formalizing a Min-Max problem of the required Quality of Service (QoS) metrics. The entailed challenges pertaining to this Min-Max problem are also given with viable solutions.

Keywords—magnetic induction (MI), wireless underground sensor network (WUSN), Quality of Service (QoS), relay selection, relay placement

I. INTRODUCTION

One of the characteristic features of underground environment as a communication medium is its inherent dynamic and unpredictable nature. Magnetic Induction (MI) has recently been widely adopted as a reliable mode of communication in this challenging environment due its unique advantages of:

i. Inter-medium communication due to constant magnetic permeability of air and water.
ii. Predictable channel response due to easy penetration and negligible multipath fading.
iii. Cost efficiency due to simple hardware (a coil).
iv. A wide variety of underground applications like seismic exploration, smart agriculture, border patrol, infrastructure monitoring (during and after construction), localization of mine workers and climate change monitoring.

MI communication operates on the principle of a magnetic field created by the current transmitted via a transmitter coil (Tx). The receiver coil (Rx) couples to this magnetic field and a MI communication link is established based on mutual induction, as shown in Fig. 1.

Fig. 1. A typical Relay Based MI-WUSN Architecture

Operating on the same principle, Near Field Magnetic Induction Communication (NFMIC) has long been used as a solution for short range communication [1]. To extend this advantageous technology to establish far-field communication, relays can be employed [2].

In this paper, we will present an overview of these relaying strategies and their respective advantages in particular applications. A literature review giving the approaches for relay deployment and their strategic advantages are given in section 2. The practical limitations and Quality of Service (QoS) requirements of the system are developed into a Min-Max problem in section 3, where the feasible approaches towards developing a solution are also given. Finally, we share our conclusion and infer future work in section 4.

II. RELATED WORK

Relays can be used as active or passive nodes in a wireless sensor network. While passive relays are merely repeaters, active relays are capable of performing some sort of digital operations on the received signal.

Active relays have been used for cooperative communication in Wireless Underground Sensor Networks (WUSN) to improve data rates and achieve spatial diversity without having to explicitly use MIMO antenna array [2]. Cooperative communication has two main operational modes:

1. Amplify and Forward (AF): The signal received at the relay is amplified and re-transmitted. However, the noise is also amplified which complicates the receiver design to enable it to correctly decode.
2. Decode and Forward (DF): The signal received at the relay is decoded and then forwarded. The error detection and correction capability of the relay complicates the hardware design.

Therefore, there is a tradeoff to the adoption of a particular relay strategy and is strictly application dependent.

Intercoil distance is critical to the operation of a MI communication system since the magnetic coupling between two consecutive nodes is determined by the internode distance, [3] has an given an experimental methodology into ‘where’ a relay node should be placed between Tx and Rx coils to improve system performance, in terms of received voltage. The experiments use a passive, waveguide-based relay system (Fig.
when relay is between transmitter and receiver (equidistant).

i. \( d \leq 2r \), when relay is placed near transmitter.

ii. \( 2r < d < 4r \), when relay is between transmitter and receiver (equidistant).

iii. \( d > 4r \), when relay is placed near receiver.

Internode distance is explored in [4] to minimize the number of relays in a linear model. It gives an innovative approach to place relays in non-equidistant way such that the first node is close to transmitter node, and then decreasing node intervals till sink, while simultaneously improving the network throughput.

Underground relay deployment and charging is also a challenging task. Using joint communication and energy scheduling techniques [5], relays can be used for Wireless Power Transfer (WPT) and Simultaneous Wireless Information and Power Transfer (SWIPT).

### III. MIN-MAX PROBLEM FOR RELAY TECHNIQUES IN MI-WUSNs

Different relay design and deployment approaches address different QoS metrics of a MI-WUSN [2]. These QoS metrics can be modelled as a Min-Max problem as given in Table I. A relay-based solution to tackle these problems is also given.

<table>
<thead>
<tr>
<th>Min-Max Problem</th>
<th>QoS Metrics and Approach to Achieve</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximize</td>
<td>Communication range</td>
<td>[1], [4]</td>
</tr>
<tr>
<td>Diversity</td>
<td>Relay selection protocols offer benefits of virtual MIMO</td>
<td>[2]</td>
</tr>
<tr>
<td>Throughput</td>
<td>Place relays by increasing the node intervals from source to sink</td>
<td>[4]</td>
</tr>
<tr>
<td>Minimize</td>
<td>Power consumption</td>
<td>[3]</td>
</tr>
<tr>
<td>Interference</td>
<td>In tri-axial coils, cross-talk can be reduced by using perpendicular coil deployment</td>
<td>[6]</td>
</tr>
<tr>
<td>Pathloss</td>
<td>Waveguides can greatly reduce pathloss for relatively long communication range</td>
<td>[7]</td>
</tr>
</tbody>
</table>

To summarize, the Min-Max problem in Table I can be solved using the following three approaches:

A. **Relay Selection Algorithms**

Relay selection algorithms can be used to scale a network, extend network lifetime, and ensure connectivity. The biggest challenge facing the development of scalable and cost-efficient relay selection algorithms is the inconsistent and unpredictable underground channel state information (CSI) in practical environment. Machine learning [2] is a powerful tool for this analysis and can be dispensed to formulate the best- and worst-case relay selection protocols.

### B. Relay Placement Approaches

Relay placement problem can be studied in terms of the required number of relays, their position and orientation [3,4,6]. The amount of processing required at a relay plays a critical role in this analysis due to the energy constraint. So, the system QoS requirements should be specified as a determinant for relay positioning. This problem becomes more critical when the nodes are mobile, for example wearsables on animals or mine workers.

### C. Optimization of Operational Parameters

For MI-WUSN, network design parameters (defined by QoS metrics) work in parallel with hardware design parameters like coil size and material etc., to solve the Min-Max problem. Their optimization requires extensive study in varying channel state conditions to determine an optimal solution.

### CONCLUSION AND FUTURE WORK

In this paper, we presented a detailed review of relay techniques and formed a Min-Max problem using the Quality of Service (QoS) metrics of a Magnetic Induction (MI) based Wireless Underground Sensor Network (WUSN). We proposed three approaches to solve this min-max problem, namely, relay selection algorithms, relay placement approaches and optimization of operational parameters.

In the future, estimation of multi-hop route (using static and mobile relays) and developing deterministic channel state models, are convincing research directions.

### REFERENCES


