Investigation of Wireless Sensor Network Coverage Implementation with Fuzzy-Logic

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Abstract—This paper presents a case study based on fuzzy-logic method for investigation of wireless sensor network coverage. The distance between sensors and sink or fusion node are considered with channel signal to noise ratio (SNR) as second parameter. Fuzzy logic method is used for implementation. Hence, the distance and channel SNR are fuzzified with appropriate membership functions. Signal to Noise ratio is based on a direct relation with Received Signal Strength Indication (RSSI) and Link Quality (LQ). The distance has crucial role on computation of RSSI with a stationary power source transmission. In this paper, the model under investigation is a Boolean sector coverage which is preciseness of received bit signal strength for correct decision making in sink or fusion node. Alteration of power transmission causes the different channel SNR due to various RSSI with different distances. The model is presented for representing coverage according to the distance with presence of AWGN. Network coverage enhancement is occurred in high SNR with close distance to receiver, while the worst coverage is happened in low SNR in maximum distance.

I. INTRODUCTION

Wireless sensor network coverage or connectivity is the most fundamental problem of communication link for delivery data signal from a sensor node in a network to sink or another node of network. Coverage and connectivity can be treated as a measure of Quality of Service (QoS) in a sensor network. One of the key parameters for link quality is power transmission budget. Indeed with high transmission power many of nodes could communicate to each other in larger scale. With constant transmission power, distances between sensor nodes have a crucial role. If the distance between two nodes exceed from a specific length, it causes lack of connectivity in direct link. On the other word, when the transmitted signal of a node due to distance and signal power attenuation could not reach to receiver node, that is called isolated node. Obviously if transmission power was enough to supply reaching to receiver node, that is fully connected node. The coverage distance as a circle region with radius $R_s$ is defined as direct relation with successful packet reception or reliability of network. Link signal to noise ratio is an important parameter for connectivity. Wireless sensor network utilizes in harsh environment with different types of possible noises for instance thermal, radiation noise. In this paper, we assumed Additive White Gaussian Noise (AWGN) type as common noise impact on signal. If power transmission increases consequently impact on SNR factor of communication link and network covers region with higher length radius and improves accuracy of data reception to sink. Constant power transmission would be covered a observing area with a specific boundary. Path loss on transmission power diminishes received signal strength and its quality at sink, hence, SNR could be a feasible parameter for study of connectivity case in coverage a observing region.

Several papers investigated coverage and connectivity issue in wireless sensor networks. In [1] the aims were to review the common strategies used in solving coverage problem in WSN. The strategies studied are used during deployment phase where the coverage is calculated based on the placement of the sensors on the Region Of Interest (ROI). In [2] the authors formulated this problem as a decision problem, which the goal was to determine whether every point in the service area of the sensor network is covered by at least $k$ sensors, where $k$ is a predefined value. Authors in [3] proposed strategies for transmission power control (TPC) in wireless sensor networks that guarantee reduction in the average power and average energy consumption. They are proposed two methods such as Fuzzy-logic based TPC (FTPC) and Markov based TPC (MTPC). FTPC utilizes the current value of Received Signal Strength Index (RSSI) and the source nodes transmission power (Ptsrc) for deciding the required transmission power (Preq). In [4] researchers attempt to bridge this gap by exploring the fundamental limits of coverage based on stochastic data fusion models that fuse noisy measurements of multiple sensors. Authors derived the scaling laws between coverage, network density, and signal-to-noise ratio (SNR). It is shown that data fusion can significantly improve sensing coverage by exploiting the collaboration among sensors.

II. PROBLEM FRAMEWORK

Wireless sensor network coverage in two dimension environment is characterized with two parameters. Signal to noise ratio and distance between two consequence nodes or a node and network sink. The problem is formulated with fuzzy logic method for an adequate investigation when parameters are varying slowly among of two maximum and minimum boundaries. A stationary distance with altering channel signal...
to noise ratio and also a stationary channel signal to noise ratio with changing distance proportionally are considered. A fuzzified distance and channel signal to noise ratio instead of max and min amounts of parameters and represent the influence of their different amounts.

A. Pathloss

According to channel model distance (d) between transmitter and receiver (FC or AP), the received power $P_r$ in dB is as follow:

$$P_r(d) = P_t - PL(d_0) - 10 \eta \log_{10} \left( \frac{d}{d_0} \right) + N(0, \sigma),$$

(1)

where $P_t$ is the output power, $\eta$ is the pathloss exponent which takes the rate of signal attenuation based on different environment obtained with empirical measurement [6]. $N(0, \sigma)$ is a Gaussian random variable with mean zero and variance $\sigma$ (standard deviation due to multipath shadowing effects). $PL(d_0)$ is the power attenuation at source and distance $d_0$ with frequency $f = \frac{v}{\lambda}, v$ is the velocity light and $\lambda$ is the wavelength. Equation (1) is an isotropic transmission [5].

B. Signal to Noise Ratio

Signal to Noise Ratio (SNR) in dB($\gamma_{dB}$) as a function of distance (meter) is expressed as:

$$\gamma(d) = P_r(d) - P_n$$

(2)

where $P_n$ is the noise floor, which reduces the power additionally, more details see [6]. With substitute consequently,

$$\gamma_{dB}(d) = P_t - PL(d_0) - 10 \eta \log_{10} \left( \frac{d}{d_0} \right) - N(0, \sigma) - P_n$$

(3)

Received Signal Strength Indication (RSSI) equation is shown in (1) and in terms of SNR from (3) can be represented as,

$$E_b/N_0 = 10^{\gamma_{dB}(d)/10}$$

(4)

$E_b/N_0$ is the received signal energy per bit per noise power spectral density, that passed through channel with relational by distance, can be expressed using the signal to noise (SNR).

C. Fuzzy logic Inference Method

Fuzzy logic inference method is performed first step with a crisp input, and then it is fuzzified with using appropriate membership functions. Fuzzy Inference Engine (FIE) is using the fuzzified data that provided from first step as fuzzy inputs. For second step rules are defined according to inputs providing for fuzzy implication process. Rule evaluations usually, in cases where a fuzzy rule has more than one conditional element (antecedent), an AND (minimum) or OR (maximum) operator is used to estimate a number that describes the result after the rule evaluation. Third step is aggregation of results obtaining from the step two with combining into the a fuzzy set based on an appropriated inference method likes Mamdani or Tsukamoto-Sugeno methods. Last step is defuzzification process that the new fuzzy set is converted to crisp number set as output. Furthermore, various methods are used e.g. Centroid method, Maximum- Decomposition method, Center of maxima.

III. IMPLEMENTATION OF PROBLEM

Implementation of the problem with fuzzy-logic can be done a process consist of, crisp input fuzzification using some appropriate membership functions. Fuzzy inputs within Fuzzy Inference Engine (FIE) perform the rules to provide inputs for fuzzy implication process. The fuzzy inference rules are chosen based on Mamdani method. Aggregation and Defuzzification FIE’s output obtain crisp output. Trapezoid-shaped membership function with corresponding expression are shown in Figures 1 and 2.

Another membership function of Fuzzy-logic is Gaussian-Shaped Function represented in Figure 3 and the corresponding expression is:

$$\mu_A(u) = e^{-\frac{(u-a)^2}{2\sigma^2}}$$

(5)

Z-shaped membership function also is used in our scenario. Figures 4 and 5 show the Z-shape function and its expression. Two input parameters are implemented based on Fuzzy Interference system (FIS), which are distance fuzzifies based on Z-shape function and SNR fuzzifies based on Gaussian-shape function. With fuzzy-logic, domains are characterized
by linguistic terms, rather than by numbers. The \( u \)-input variable of each membership function should be assigned with appropriate boundary for min and max corresponding to linguistic assignment. Input parameters are computed to signify numeric boundaries and linguistic variables.

**IV. SIMULATION RESULTS**

Implementation of fuzzy logic fusion is performed using Fuzzy Logic Toolbox in Matlab GUI. Fuzzy Interference System (FIS) is done with two inputs as distance (m) and SNR (dB). Distance is in range: 1 to 100 meters and SNR is in range : 3 to 12 [dB]. Inference performs based on Mamdani method. Gaussian membership function, Z-shaped membership function, Trapezoid-shaped membership function are used to defining input value of SNR, input value of distance and output value of coverage, respectively. Different range of SNR and distance and coverage are characterized by linguistic terms which are explaining behavioral of fuzzy parameters in corresponding ranges. ’18’ rules are implemented with ’AND’ logical operator to specify output. Inference operands method as defaults lists as follow:

- Or method = min,
- AND method = max,
- Implication = min,
- Aggregation = max,
- Defuzzification = centroid.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum distance</td>
<td>1 meter</td>
</tr>
<tr>
<td>Maximum distance</td>
<td>100 meters</td>
</tr>
<tr>
<td>Power Tx</td>
<td>3 dBm</td>
</tr>
<tr>
<td>Noise</td>
<td>-5 dBm</td>
</tr>
<tr>
<td>Band width</td>
<td>30 kHz</td>
</tr>
<tr>
<td>Signal frequency(f)</td>
<td>2450 MHz</td>
</tr>
<tr>
<td>Path loss exponent</td>
<td>4</td>
</tr>
<tr>
<td>Shadowing standard deviation</td>
<td>4</td>
</tr>
</tbody>
</table>

### TABLE 1

PARAMETERS VALUE FOR PATHLOSS

\[
\mu_A(u) = \begin{cases} 
1 & \text{for } u \leq a \\
1 - \frac{(u-a)^2}{(a-b)^2} & \text{for } a > u \leq \frac{a+b}{2} \\
2 (b-u)^2 & \text{for } u > \frac{a+b}{2} \& u \leq b \\
0 & \text{for } u > b 
\end{cases}
\]

**Fig. 3. Gaussian-Shaped membership function**

**Fig. 4. Z-shaped Membership Function**

**Fig. 5. Z-shaped Membership Expression**

**Fig. 6. Gaussian Membership Function of SNR**

**Fig. 7. Z-shaped Membership Function of Distance**
Schematic of membership functions used in simulation are shown in Figures 6, 7 and 8. Linguistic variable is assigned base on boundary of parameters impact on network coverage. For instance, linguistic set \{medium, good, excellent\} assigned to signal to noise ratio membership function for Min = 3 [db] and Max = 12 [db] for each 4 [db] increasing signal power rather than noise power. Same scenarios for distance linguistic variable also is made whereas set\{poor, verygood, good, excellent\} for Z-shaped membership function assigned correspondingly to boundary of parameter impact on network coverage with Min = 1 meter and Max = 100 meters. Boundaries are represented in Figure 7 for distance and illustrated in Figure 6 as signal attenuation boundaries or SNR. Then are computed based on RSSI expressions indicated from (4), (1) and (2). Output is assigned with linguistic with five members of set \{poor, good, verygood, perfect, excellent\}. Those give more information on the consequence of fuzzy implication process.

Network coverage is shown in Figure 9. As mentioned Mamdani inference rule method was used for implementation of 3D simulation of network coverage based on two function attenuation of signals, distance and SNR. Figure 9 represents their impact on network coverage.

**Fig. 8. Trapezoid-shaped Membership Function of Network Coverage**

**Fig. 9. Network coverage as function of SNR, Distance**

**V. CONCLUSION**

The aim of this paper was an investigation on network coverage with fuzzy-logic method. Generally speaking, network coverage is crucial issue when sensors belong to a network need to communicate with each other and collection of sensing information for decision making transmitted to network sink or fusion center. Therefor, two significant parameters, namely distance and Signal to Noise ratio are considered. They are fuzzified and based on FIS with utilization of Mamdani method. Consequently, close distance and high transmission signal power (in proportion to noise power) has better coverage and connectivity. High transmission power is not very feasible with respect to Battery power constrain in sensor node, thus, it should have a proportional relation between two parameters distance and signal to noise power. Reliability of received data signal would be guaranteed when proportional relation have been concerned. this would be very important since the decision will precisely be taken based on received signal.

**REFERENCES**


