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Wireless Channel-Quality Estimation with Fuzzy and Kalman Filters to Evaluating Network Performance Metrics

Saeed Havedanloo* and Hamid Reza Karimi*

ABSTRACT

Channel quality is a vital parameter in wireless networks. Performance evaluation such as packet reception and packet dropout are related to quality of wireless channel. Estimation quality of wireless channel is investigated with utilizing a Kalman filter and Fuzzy system as two comparative methods. Quality of channel is considered with Received Signal Strength Indication (RSSI) estimation and NOise Indication (NOI) in order to evaluating Signal to Noise ratio (SNR). The proposed schemes represent the minimization error to assessment of SNR as an infiuential parameter of channel. Network within an area of observation is assumed with mobile sensor nodes across them. Number of sensors organized into clusters is not fixed particularly. Fusion Nodes (FN) as head of each cluster is used to fuse the received data based on estimation of RSS with a Kalman filter with respect to a specific constrained level of signal strength. Fuzzy controller is proposed to estimate amount of Singal to Noise Ratio (SNR) and is stored in a table for utilizing data in Markov Model. A Markov Chain Model of IEEE 802.15.4, with MAC and PHY cross-layer is considered for evaluation of performance mertic according to the estimation schemes. The evaluation is presented to demonstrate the efficiency in accuracy with Bit Error Probability (BEP) and reliability of network.

I. INTRODUCTION

Wireless Sensor Networks (WSNs) have been highly promoted recent years. Remote operation, monitor various environment in large scale industrial, military, health and logistics systems (Ship, Truck, e.g.), RFID, heterogeneous robotic platforms are just some of applications of WSNs. WSNs also have critical role in Automation and Networked Control System (NCS) for enhancing the observability and controllability of physical parameters in the environment. Deployment of WSNs encounter with several challenging issues especially while sensor nodes would be mobile. Routing of coming data to specific target node, accuracy of received data for target tracking or fusion for making decision could be significant challenges. Received Signal Strength Indication (RSSI) is an important parameter in Channel Quality (CQ) evaluation. Link Quality Indicator (LQI) is an assessment reference which indicates the received data packets quality to receiver. The RSS can be employed for a characteristic of signal quality. Total energy of received signal would be indicated as Received Signal Strength Indicated(RSSI) consisted of the RSS and Noise energy. The proportion of desired RSS versus in-band noise energy is Signal to Noise Ratio (SNR) as a significant parameter to judge quality of channel. Basically, higher SNR is considered as an interpretation of lower chance of packet failure. Thus, the channel with high SNR is named as a high-quality Link. Additionally, signal energy level is another parameter for LQ as accuracy point of view. The LQI occurs in physical layer and reports information to higher layers such as Medium Access Control (MAC), Network (NWK) and Application Layer (APL) for any type of analysis and decision. For instance, NWK layer can use the LQI report to decide which path to use for routing a packet data. This would be more important while the

* Faculty of Engineering and Science, University of Agder N-4898 Grimstad, Norway, *E-mails: saeedh09@student.uia.no; hamid.r.karimi@uia.no*

sensors are mobile and need to find better stream data route. Mobile sensor node in a star network topology transmits sample sensing data to corresponding sink node according sufficient range of indication for RSS; however, when the sensor nodes are mobile into the multi-clusters area of under observation in a network, presence of multiple cluster heads would be more efficient than a star network just by one sink node. Several cluster heads with fusing role also need more exact received signal data, hence, accurate estimation of RSS takes into to account.

Area of observation in large scale needs a grid of observing sensors with fiexibility in movement, distance would be an important parameter for reception data in FNs accurately. Due to mobility of sensors and their moving beyond of their clusters and inter into neighbor clusters, RSS into arriving cluster could be stronger than coming cluster therefor corresponding cluster head or FN estimates RSS and compares with a threshold level to accept or reject signal data. Estimation of Received Signal Strength (RSS) is performed in Fusion Nodes (FNs) with utilizing Kalman filter or fuzzy-controller and evaluates the channel characteristics of wireless links as a function of the signal-to-noise ratio (SNR). Thus, firstly we measure quality of channel with the proposed schemes thereafter Channel State Information (CSI) woluld be evaluated with an estimation schemes results; and secondly performance metric of network is appraised in terms of packet failure as Bit Error probability (BEP) assessment or packet dropout and reliability of network with respect to a Markov Chain Model of MAC-PHY cross-layer of sensor network originally proposed in [3].

II. RELATED LITERATURES SURVEY

Several researches attempted to evaluate performance metric of network with respect to different schemes, for instance, in [1] authors proposed a performance metric evaluation for a distributed detection wireless sensor network with respect to IEEE 802.15.4 standard. A distributed detection scheme is considered with presence of the fusion node and organized sensors into the clustering and non-clustering networks. Channel State Information (CSI) specifications are investigated with respect to a stationary distance and constant number of sensors in each cluster. Fusion centers are acting as head of clusters for decision making based on majority-like received signal strength (RSS) in comparison to the optimized value of the common threshold. IEEE 802.15.4 Markov chain model derived the performance metric of proposed network architecture with MAC, PHY cross-layer parameters and Channel State Information (CSI) specifications while it is including Path-loss, Modulation, Channel coding and Rayleigh fading. In [2] authors analyzed the performance of a mobility-aware MAC protocol named CM-MAC for large scale cluster-based WSNs, somehow, it can select new cluster-head with an algorithm and choose a priority-based bit-map-assisted (BMA) scheduling strategy. In this paper, a cluster based Mobile nodes scheme is proposed with an estimation of link-quality using a Kalman filter in FNs. Received data consequently would be utilized for decision-making purposes. A Markov Chain is considered for performance analysis of Network by using outcome of estimation. In [4], the authors considered a proposal with a Triangle Metric, a metric that combines geometrically the information of PRR, LQI and SNR into a robust estimator that guarantees a fast and reliable assessment of the link quality. In this work, the evaluation shows that the triangle metric can identify the quality of links using as few as 10 packet samples, making it an eligible solution for highly mobile sensor networks. It is noting that geometrical method is not used for estimation. As is mentioned before, a Kalman filter method is considered for LQ estimation. Another work in [5] presents an empirical study showing that an improved indicator, termed Effective-SNR, can be produced by combining Signal to Noise Ratio (SNR) and Link Quality Indicator (LQI) with minimal additional overhead. The estimation accuracy is further improved through the use of Kalman filtering techniques. Finally, experimental results demonstrate that the proposed algorithm can be implemented on resource constraints devices typical in WSNs. It introduces several related works channel estimation methods designed for operation in wireless communication network, most of them basically focused on enhancement of accuracy. Also in [6] authors address a state estimation problem over a large-scale sensor network with uncertain communication channel.

Consensus protocol is usually used to adapt a large-scale sensor network. However, when certain parts of communication channels are broken down, the accuracy performance is seriously degraded. Specifically, outliers in the channel or temporal disconnection are avoided via proposed method for the practical implementation of the distributed estimation over large-scale sensor networks. This paper handles this practical challenge by using adaptive channel status estimator and robust L1 -norm optimization by Kalman filter in design of the processor of the individual sensor node. Then, they are incorporated into the consensus algorithm in order to achieve the robust distributed state estimation. The robust property of the proposed algorithm enables the sensor network to selectively weight sensors of normal conditions so that the filter can be practically useful.

III. PROBLEM FRAMEWORK

Wireless sensor network communicates through channel with assuming presence of Adaptive White Gaussian Noise (AWGN), in such a realistic channel model, An important issue is to determine performance of link. Usually, deterministic distance-dependent and threshold-based packet capture channel models are assumed as two methods of data reception. Receiver is located outside of the circle connectivity with radius distance Rd can not receive packets due to non-profitable signal strength. The thershold-based reception model catches data packets while SNR is higher than a specific threshold [11]. Capacity of link can be estimated by SNR parameter with a good approximation. Bit Error Rate (BER) describes in probability of error in received bits of a data stream over a communication channel due to differs in signal to noise, interference, distortion or bit synchronization errors. This parameter actually is shown as a bit error rate probability pe with respect to this reality that approximately estimates failure of bits. At noisy model channel with AWGN without fading, the BER is represented as a function of carrier-to-noise ratio measure denoted E_b/N_0, (energy per bit to noise power spectral density ratio), or E_s/N_0 (energy per modulation symbol to noise spectral density). Wireless Sensor Network based on IEEE 802.15.4 mechanism in 2.4 GHz band and Offset quadrature phase-shift keying (OQPSK) modulation bit error rate is expressed by [7],

$$BER = \frac{1}{2} er\ fc\left(\sqrt{\frac{E_b}{N_0}}\right) \tag{1}$$

whereas *erfc* is Gauss error function. In order to depict the energy per bit to noise power, since the sensor creates a bit data with adequate constant transmission power and send it through the channel an infiuential attenuator parameter is distance between Transmitter (T_x) and Reciever (R_x). *Path loss* in communication link should be taken into account for measurement power loss due to distance. In reality, signal power could distort with several environmental parameters including Fading and

Table I
Received Signal Strength Indication in Different Disatce

Distance(m)	$d_1 = 5$	$d_2 = 10$	$d_3 = 15$	$d_4 = 20$	$d_5 = 25$	$d_3 = 30$
RSSI(dbm)	–49.22	–53.40	–56.89	–62.38	–66.01	–71.32

Shadowing. Both effects have various impact with respect to environments incidence. For instance, magnitude impacts of *fading* and *shadowing* in industrial building and equipments completely differ with battle ground or inside of hometown with high building. While Mobile sensors in a limited area are moving and their data generation should reach to especial Access Point (AP) or a decision center according to time and position. Several Intermediate nodes (Call Fusion Centers (FCs)) are fusing data in heads of corresponding clusters. FCs also can improve signal power and boost it to forward to another node or to access point. The sensor nodes can move among a cluster or beyond of it in whole of observing area as well as inters to other clusters. According this dynamic circumstantial, fusing the data would be happened at corresponding FC based on position of sensor into the cluster. However, in wireless fading channel sensor network is difficult to accurately illustrate SNR with respect to distortion in signals. Notwithstanding, system capacity in fading channel usually needs high complexity analytical modeling that cannot be afforded by resource constraint in WSN platforms [5]. As consequence, we attempt to propose an estimation method of channel quality with Kalman estimator for wireless sensor nodes in a network observating a environment. The Link Quality (LQ) is evaluated and substituted into a performance metric chain Markov model of IEEE 801.15.4 MAC-PHY layer network that basically proposed in [1]. IEEE 802.15.4 Markov chain model with manipulation yields performance metric expressions such as Packet failure as BEP parameter and success received packet or reliability of network (see [1], [3]).

In propagation model, terrestrial communication link conditions can effect on quality of signal. In free space, if those effects can be neglected for simplicity, hence, well-known *Friis* equation can be used to declare ratio of power input of the receiving antenna, P_r, to the output power of the transmitting antenna, P_t and indicates the *power loss* between transmitter and receiver antenna connectors as a relation with distance d and the electromagnetic wavelength λ,

$$\frac{P_r}{P_t} = GT_x \cdot G_{R_x} \cdot \left(\frac{\lambda}{4\pi d}\right)^2, \tag{2}$$

Also it can be written as,

$$P_{loss}(d) = \frac{1}{G_{T_x} \cdot G_{R_x}} \cdot \left(\frac{4\pi d}{\lambda}\right)^2, \tag{3}$$

where G_{T_x} and G_{R_x} represent the transmit and receive antenna gain, respectively.

According to Narrowband channel model, path-loss conventionally is defined for distance (d) between transmitter and receiver (FC or AP), the received power P_r in dB is as follows:

$$P_r(d) = P_t - PL(d_0) - 10\,\eta \log_{10}\left(\frac{d}{d_0}\right) + N(0,\sigma), \tag{4}$$

$$PL(d_0) = 20 * log_{10}(f)$$

where P_t is the output power and η is the pathloss exponent which takes the rate of signal attenuation based on different environment obtains with empirical measurement [12]. $N(0, \sigma)$ is a Gaussian random variable with mean 0 and variance σ (standard deviation due to multipath shadowing effects). $PL(d_0)$ is power attenuation at source with distance d_0 with frequency $f = \frac{v}{\lambda}, v$ is velocity light and λ is wavelength. Equation (4) is an isotropic transmission. *SNR* in $dB(\gamma_{dB})$ as a function of distance (meter) is [1]:

$$\gamma(d) = P_r(d) - P_n \tag{5}$$

where P_n is noise fioor, more details see [12]. With substitute consequently,

$$\gamma_{dB}(d) = P_t - PL(d_0) - 10\,\eta \log_{10}\left(\frac{d}{d_0}\right) - N(0,\sigma) - P_n, \tag{6}$$

Two methods for channel-quality estimation would be proposed in coming sections.

(A) Fuzzy Controller System

Wireless Channel Quality (CQ) is evaluated base on Signal to Noise ratio parameter. CQ is an element of Link Quality Estimation (LQE). Fuzzy controller is proposed for estimation of SNR in channel. Measured SNR in dB is stored in a data mining table and based on mobile sensors in distances. Indicated RSS and NO could be retrieve correspondingly amount of Signal to Noise ratio. Thus, retrieved data can be used in Mathematical Markov model of IEEE 802.15.4 equations for evaluating performance metrics of network. Fuzzy logic inference method is performed first step with a crisp input, and then it is fuzzificated with using appropriate membership functions. Implementation of fuzzy system with respect to proposed strategy is carried out by assigning appropriated membership functions to RSSI, NOI and desired output SNR respectively. 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. Basically, human knowledge is important characteristic in fuzzy systems. Linguistic terms are used to represent on boundary of parameters impact assessment of SNR [11].

$$\mu_A(u) = \begin{cases} 0 & \text{for } u \le d \\ \dfrac{u-d}{e-d} & \text{for } d \le u \le e \\ 1 & \text{for } e \le u \le f \\ \dfrac{g-u}{g-f} & \text{for } f \le u \le g \\ 0 & \text{for } u \ge g \end{cases}$$

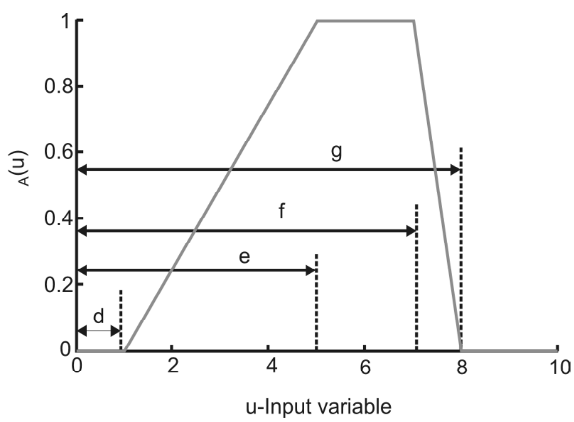

Figure 1: Trapezoid-Shaped Membership Function

(1) Implementation of Fuzzy-System 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 Mamedani method. Aggregation and Defuzzification FIE's output obtian crisp output. Trapeziod-shaped membership function with corresponding experssion is shown in Figures 1.

Another membership function of Fuzzy-logic is Gaussian-Shaped Function represents in Figure 3 and the coressponding experssion is:

$$\mu_A(u) = e^{\frac{-(u-a)^2}{2b^2}} \tag{7}$$

Figure 2 shows the Z-shape function and its experssion.Two input parameters are implemented for Fuzzy Interference system (FIS), which are Noise Indication (NOI) fuzzifies based on Gaussian-shape function and Received Signal Strength Indication (RSSI) fuzzifies with Z-shape membership function. With fuzzy-logic, domains are characterized by linguistic terms, rather than by numbers. The u-input variable of each membership function should be assinged with appropriated boundary for min and max corresponding to linguistic assigment terms. Initianlly,Input parameters are computed to signify numeric boundaies and linguistic variables with respect to human knowledge precedence.

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

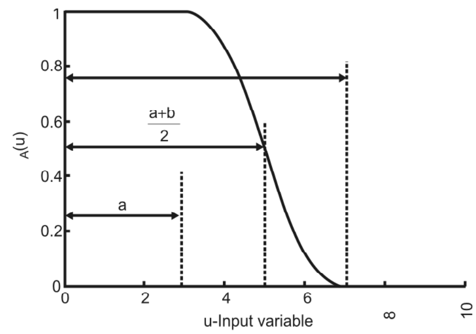

Figure 2: Z-shaped Membership Function

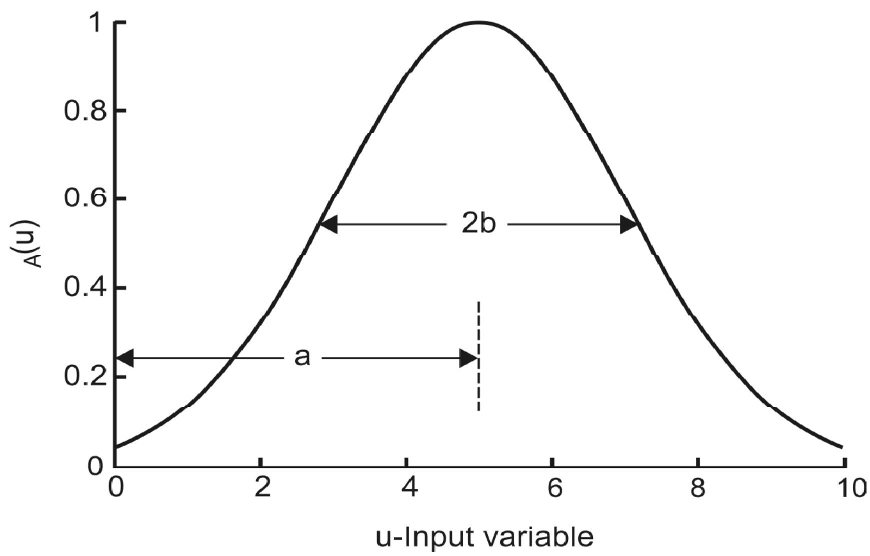

Figure 3: Gaussian-Shaped Membership Function

(B) Kalman Filter Design

Chnnel-quality clearly discussed in pervious sections has dynamic and time-varying system. Noise measurement is a crucial fact according to various propagation environments. Enhancement of estimation channel quality parameters gives possibly to mitigate noise impacts and channel inconvenient affects. Estimation (track) channel parameters and states is considered with deployment of a Kalman filter. System inputs are non-linear in a dynamic system, hance, a Kalman filter should be taken into the account support this circumstance. An Extended Kalman Filter (EKF) can be suitable for such a system. However, designed system with EKF requires high computation, thus, EKF is not sufficient for wireless sensor network with limitation in resources. Received Signal Strength (RSS) power (P_r) and environment Noise (N_r) are two parameters for estimation.

$$H=\begin{cases}P_{r,k}=P_{r,k-1}+W_{s,k}\\ N_{r,k}=N_{r,k-1}+W_{n,k}\end{cases} \tag{8}$$

where, W_s and W_n are environment noise and fading influnce on signal with independent zero mean Gaussian distributions, respectively. Equation (8) can be rewritten in matrix form corresponding to state evaluation with respect to state variable of dynamic system, $x=\begin{bmatrix}P_r\\ N_r\end{bmatrix}$ as follows:

$$x_k = A.x_{k-1} + W_k \tag{9}$$

where $A = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and $W_k = \begin{bmatrix} W_s \\ W_n \end{bmatrix}$, observation equation is:

$$y_k = C.x_{k-1} + v_k, \tag{10}$$

where $y = \begin{bmatrix} RSSI \\ NI \end{bmatrix}$

The state-space model setup eqs (8) – (9) as designs with a kalman filter.

PriorUpdate: $x_{\bar{k}} = A.x_{\bar{k}-1}$

PriorErrorCovariance: $P_{\bar{k}} = A.P_{k-1}.A^T + Q$

$$KalmanGain: \; K_k = (p_{\bar{k}}.C^T).(C.P_{\bar{k}}.C^T + R)^{-1} \tag{11}$$

PosteriorUpdate: $x_k = x_{\bar{k}} + K_k.(y_k - C.x_{\bar{k}})$

PosteriorErrorCovarince: $P_k = (I - K_k.C).P_{\bar{k}}$

here, $x_{\bar{k}}$ is the a priori estimation of state, x_k is the a posteriori estimation of state. $p_{\bar{k}}$ is the a priori estimation of error covariance and $\bar{p}$ is a posteriori estimation of error covariance. K_k is the Kalman gain. Q and R are the variance of state noise and variance of measurement noise, respectively [5].

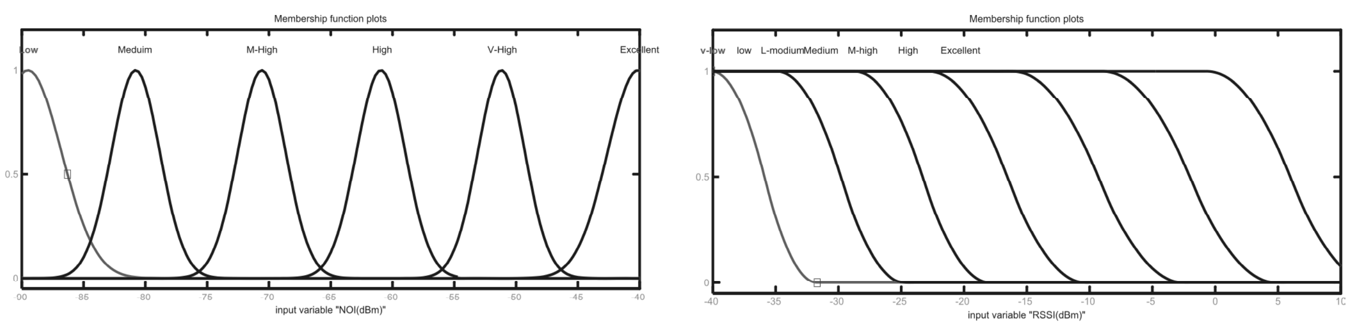

Figure 4: Membership Function for Fuzzy-Inputs, RSSI, NOI

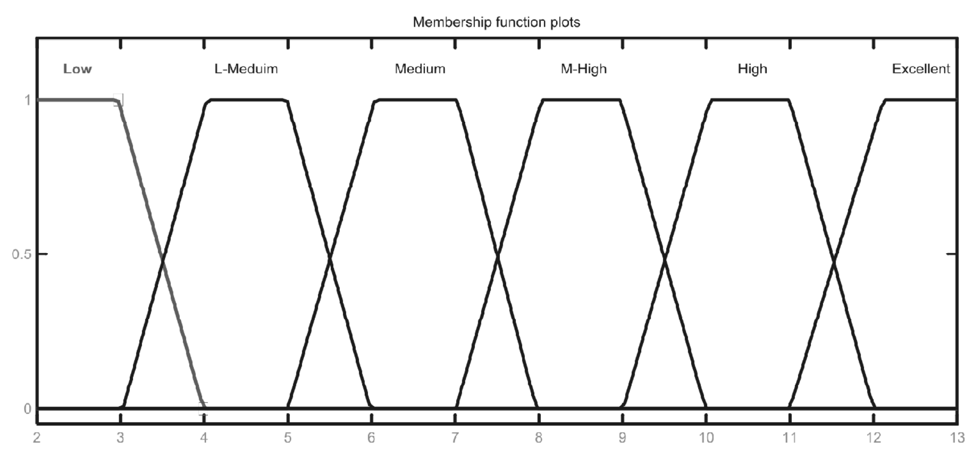

Figure 5: Membership Function for Fuzzy-Output, SNR

IV. SIMULATION RESULTS

Simulation performs based on a low-cost network with low battery resource. Environment noise assumed as regular urban with presence of noise. Power resource as an important parameter of a network is considered low-utilized system. Three power are set up transmitter with –15, –35, –50 dBm. Those are very low consumption power transmitter that we assumed. Signal to noise ratio (SNR) is presented versus environmental noise power that growing form –75 [dbm] to –45 [dbm] in Figure 7.

Implementation of fuzzy logic fusion is performed using Fuzzy Logic Toolbox in Matlab GUI. Fuzzy Interference System (FIS) is done with two inputs as RSSI (dBm) and NOI (dBm). RSSI is in range: –40 to 10 [dBm] and NOI is in range : –90 to –40 [dBm]. SNR is output in [dB]. Inference engine performs based on Mamdani method. Gaussian membership function, Z-shaped membership function, Trapezoid-shaped membership function are used to defining input value of , inputs value of NOI, RSSI and output value of SNR, respectively. Different range of all inputs and output are characterized by linguistic terms which are explianing behavioral of fuzzy parameters in corresponding ranges. ′44′ rules are implemented with ‘AND’ logical operator to specify output. Inference opreands method as defaults lists as follow:

Or method = min,

AND method = max,

Implication = min,

Aggregation = max,

Defuzzification = centriod.

Schematic of membership functions used in fuzzified simulation are shown in Figures 4, 5. Linguistic variable is assigned base on boundary of input parameters impact on output SNR evaluation. For instance, linguistic set consist of VeryLow, Low, Low-medium, medium, Medium-high, High, excellent assigned to specific boundries of RSSI membership function. Same senarios for NOI linguistic varible also is made whereas set $\{Low, Medium, Mhigh, High, VeryHigh, excellent\}$ membership function assinged correspondingly to boundary of parameter. Boundaries represent evaluted parmeters for Z-shaped, Gussian and Trapeziod-shaped membership functions Figure 4 for NOI and RSSI and 5 for boundaries of SNR. Output is assigned with linguistic with five memebers of set $\{Low, L-medium, Medium, M-high, excellent\}$. Those give more information on the consequence of fuzzy implication process.

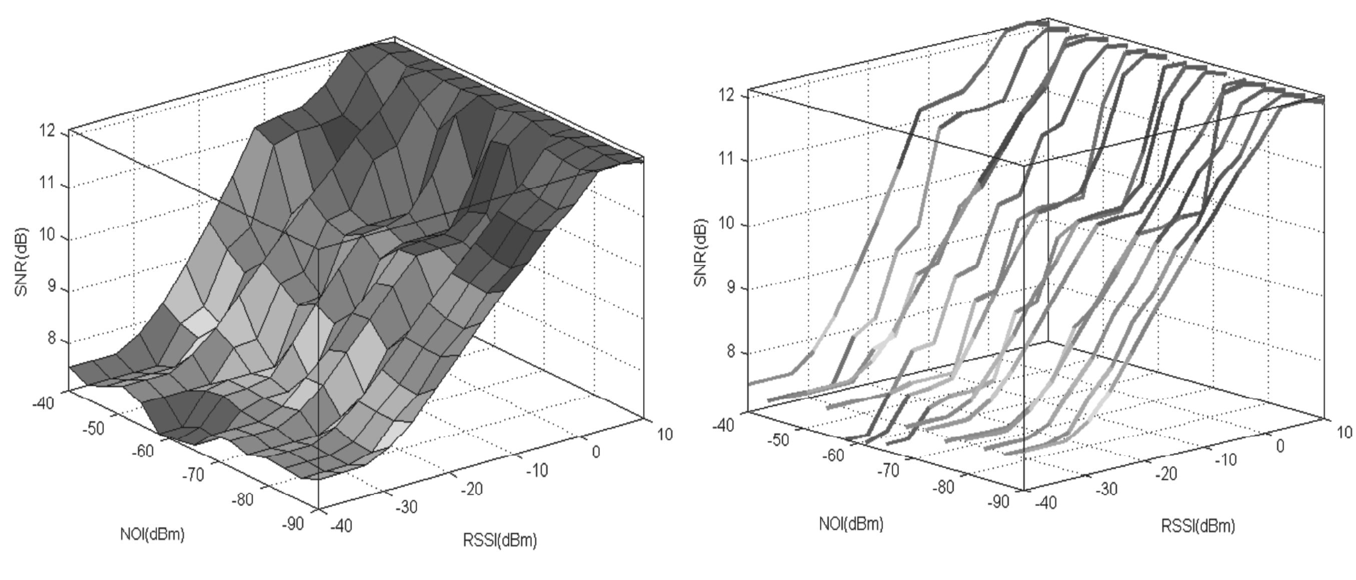

Figure 6: Fuzzy Estimation of Signal to Noise Ratio

Channel Signal to Noise Ratio [dB] is shown in Figure 6, 7. As mentioned Mamdani inference rule method was used for implementation of 3D simulation of SNR based on two function RSSI, NOI.

Estimation of SNR according to Kalman filter was calculated with two inputs Received Signal Strength Indication (RSSI) and Noise indication (NI). Figure 7 represents the Actual and Estimated Signal to noise ratio. It illustrates the improvement in estimated ratio of channel signal power to noise power. Simulation carried out with assumation parameters for physical and MAC layer which mentioned in Table II , III respectively. Those parameters are used in implementation Markov model PHY-MAC cross layer IEEE 802.15.4 that is orginally proposed in [3] and more investigated in [9].

Markov Model for IEEE 802.15.4 Medium Access Channel (MAC) implemented cross PHY MAC layer in previous work [9] used for evaluation performance metric as Bit Error Probability (BRP) and Reliability. Reliability is probability of success packet reception in receiver refer to [3]. Figures (8) and (9) show Bit Error Probability and Reliability respectively. The evaluation is carried out with substitute estimated SNR a long with actual SNR measurement. Simulation assesses high data rate with generation of bit stream. High data rate with low power consumption in the noisy environment represent in both figures 9 and 8.

A network with ‘32’ nodes was provides network bit rate. Nodes in network are mobile and changes thier locations inside a circle area with beam mimimume 1(m) to maximum 40(m).

Fusion node or sink is located in center of coverage circle. Table I is represent calculation of received signal strength in a circle in different distance from fusion node. Obviously, since the node would be far from center of circle coverage received power from transmitter to fusion node is reduced and consequently distance has significant impact on accurcy of data bit receives to fusion node and directly infiunce on decision making. Reliablity of network reduces while network sample is high rate but the estimation with kalman filter gives better performance and reliabilty of network. Bit error probability has also better results with respect to estamiation reduced percentage of bit failure as consequence packet drop out whould be mitigated through channel and network to increase the accuracy and efficiency.The impact of channel condition or channel state information (CSI) and link quality is significant on decision which would be made at fusion node. In addition to sensor observation quality, probability of decision error (P_e) at FC completely is related to channel condition and Received Signal Strength Indication (RSSI). Direct relation between probability of success packet reception or reliability, with probability of packet failure or BEP are shown in Figures, has consequent improvement on reliability with estimation term. Enhancement of SNR in estimation process causes less failure packet reception at fusion node. As Result it represents imporvment of decision error.

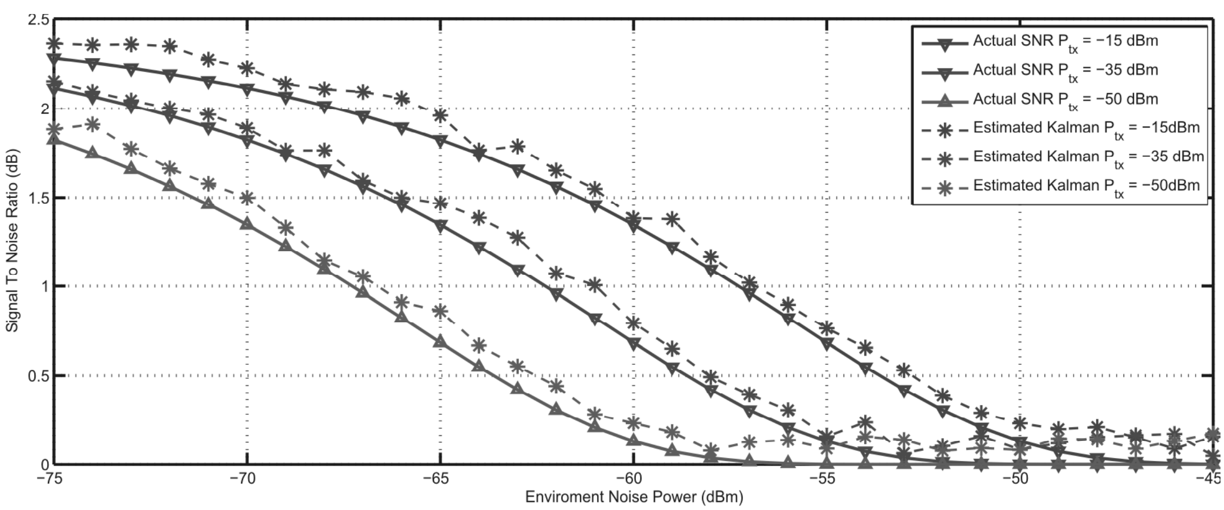

Figure 7: Kalman Estimation of Signal to Noise Ratio

Table II
Parameters Value for Physical Layer

Parameter	*Value*
Minimum distance	1 meter
Maximum distance	40 meters
Power Tx	–40 dBm
pramble length	40 bits
Noise figure	–105 dBm
Noise Mean	–75 dBm
Band width	30 kHz
Signal frequency (f)	2450 MHz
Path loss exponent	4
Shadowing standard deviation	4

Table III
Parameters Value for MAC Layer

Parameter	*Value*
MacMaxFrameRetries(n)	3
MacMaxCSMABackoffs(m)	4
MacMinBE(m_0)	3
MacMaxBE(m_b)	5
t_{ack}	222e-9 seconds
t_{IFS}	640e-6 seconds
$t_{m,ack}$	200e-9 seconds
aUnitBackoffPeriod	320e-6 seconds
macACKWaitDuration	1920e-6 seconds
aTunaroundTime	192e-6 seconds
S_b	128e-6 seconds
L_0	10e-12
W_0	$2^{macMinBE}$
q_0	10e-12

V. CONCLUSION

This paper investaged the estimation of wireless channel-quality with Kalman filter and fuzzy controller system to evolution of performance metric for mobile sensors in observing area of interest. The authors' aim was to show impact of estamation of a fuzzy controller and Kalman filter in reciever side for assessament of signal strength. Actual method is investagted too and compared with estimation method. Fuzzy system and Kalman filter in the same bandwidth and data rate more has accurately process and efficient performance. Link-quality is an assessment reference method which indicates the received data packets quality to receiver. Signal to Noise Ratio (SNR) is as a significant parameter to determine quality of channel. Base on our work, both estimation of Kalman filter and fuzzy system improve the quality of link according to paramter reliabilty and Failure probability or Bit Error probability (BEP) which discussed in pervious section. Performance metric evalution is performed with substitution of estimation and actual calculation of SNR in Markov model of IEEE 802.15.4 PHY-MAC corss layer and Channel State Information (CSI) specifications

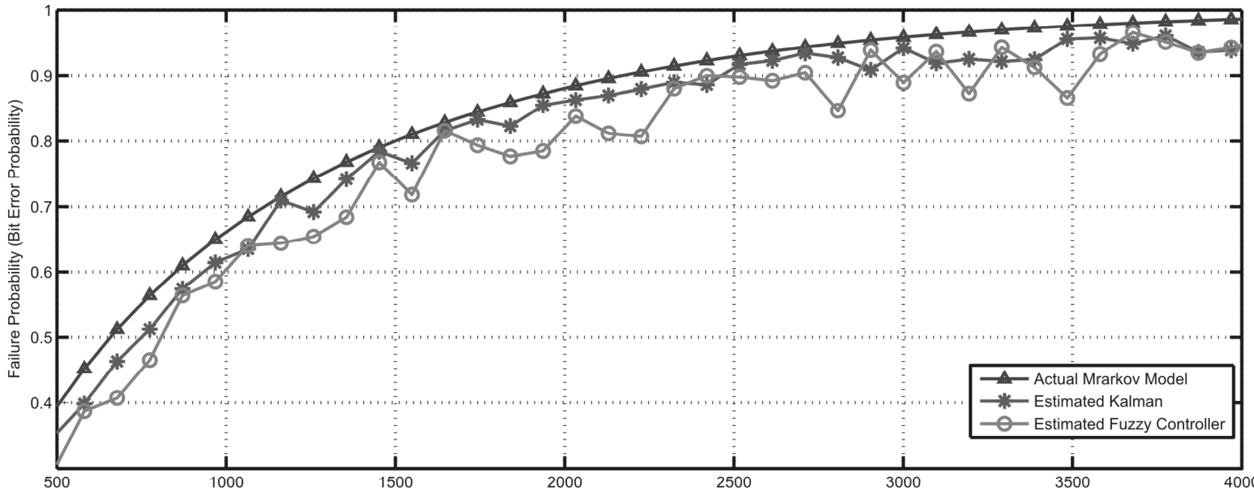

Figure 8: Bit Error Probability vs Bit Generation Rate per Node

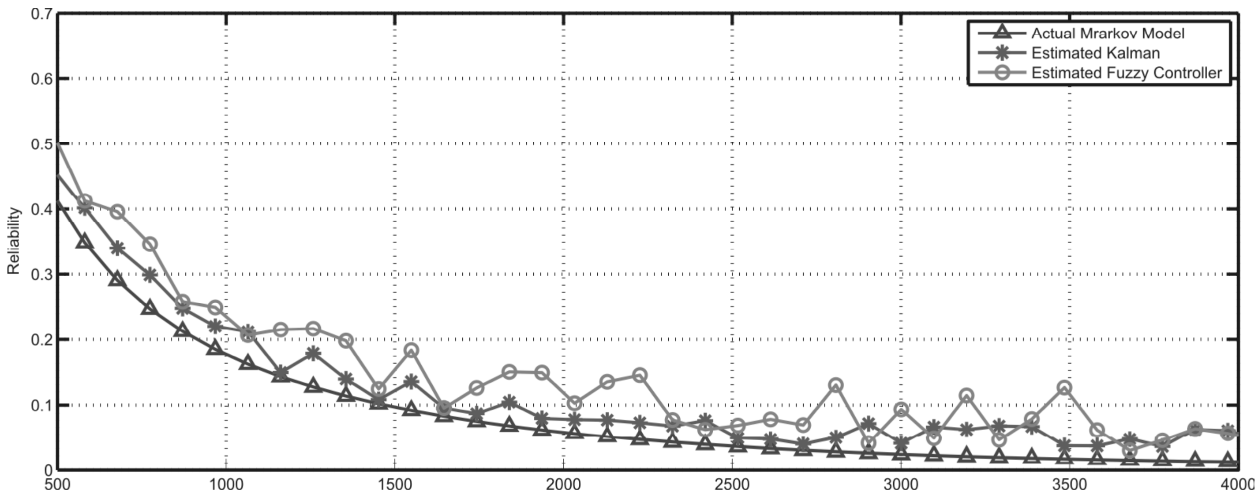

Figure 9: Network Reliability vs Bit Generation Rate per Node

while shows maximum achievable throughput of a wireless link at different transmission rates. This result has the potential to significantly improve the performance of routing process and transmission rate adaptation algorithms.

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