Kalman Filtering of Link Quality Indicator Values for Position Detection by Using WSNS

Baki Koyuncu, and Pejman Panahi

***Abstract*—**Kalman Filtering plays an important role in reducing random variations of RF signals. LQI values represent the RF signal strengths with respect to distances. Kalman Filtering is applied on LQI values in real time to reduce the random variations due to environmental factors. Kalman Filtered LQI values are used in position detection. Localization accuracies are improved with Kalman Filtering compared to LQI values without Kalman Filtering. Kalman filtering is applied on 1 dimensional LQI data**.**

Keywords**--**Kalman Filter, LQI, RF signals, Localization, WSNs

I. Introduction

RADIO Frequency technology is used in various applications to detect object location with wireless sensors [1,2]. Wireless sensor transmitters transmit radio signals and they are received by wireless receivers at various distances. Received signals are arrived in the form of Link Quality Indicator, (LQI). Peripheral effects may cause temporal variations with signals strengths. Other environmental effects such as temperature, weather conditions or obstacles also affects the received signals similar to these peripheral effects.

In RF based position detection systems, there are two types of measurements. In first model, receiver on the object receives RF signals from surrounding transmitters,[3,4]. In second model, transmitter on the object transmits RF signals to well placed receivers across the test area. In both cases, RF signals are affected by environmental effects. Scientists would like to reduce or eliminate these RF signal amplitude variations in order to carry out correct localizations, [5,6].

There are many attempts in literature to reduce the variations in recorded RF signal amplitudes by using filtering techniques [7]. Filters pass the required signals with minimum attenuation within the given frequency bandwidths and stop those unwanted signals to near zero values outside the frequency bandwidths. Signal amplitude variations within the passband are called ripples and they are required to be as small as possible.

Kalman filtering,[8], is a set of mathematical equations which provides an efficient way to estimate the state of a dynamic system.

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It is also known as Linear Quadratic Estimation (LQE) technique. Kalman Filtering uses series of measurements observed over time, containing noise and other inaccuracies, and produces estimation of variables about system's unknown state [8]. In conclusion, Kalman filter operates recursively on streams of noisy input data to produce optimal estimation about system‘s state.

Kalman filter algorithm, [9], is developed by Rudolf Kalman in 60's. The algorithm works in a two steps. First step is called prediction step and in this step system's next state is calculated by using system's past values and past measurements. The second step is called time-measurement step and in this step, old values are changed with new values recursively.

Kalman filter is basically a predictor. Its algorithm uses the current and past system state values and predicts the next state about a dynamic system [9]. As in general filter systems, Kalman filter has a filtering property and it has a powerful algorithm to predict the system's non measurable state value. General design methodology for such a filter requires a full description of noise affecting the states and measurements [10].

Kalman filter has various technological applications. Most commonly used areas are in navigation, military and car tracking systems. Weather prediction all year round is another well known application.

In mathematical terms, Kalman filter estimates the states of a linear system. It works well in practice and it is theoretically attractive because it minimizes the variance of the estimated error among all possible filters [4]. Kalman filter algorithm is based on a mathematical model. This model needs to assume a start value of the system. Kalman filters are mostly implemented in embedded control systems to control a process, which one needs an accurate estimate of process variables.

Initially, an application program is developed for recording LQI values at various points across the test area. These LQI values are later stored in a database in a server computer. Recorded values are filtered with Kalman filtering technique. Filtered and non filtered LQI data are utilized in position detection procedures and positioning accuracies are compared.

This paper is organized as follows. In 1st section, introduction about Kalman filtering is given. In section 2, an understanding of LQI value is given. In section 3, theory of Kalman filtering technique is explained. In section 4, implementation of the technique is presented. In Section 5, conclusions are given.

II. LQI AND RSSI

Radio signal propagation has a complicated nature and received signal strength values are difficult to calculate. Incoming RSS values are measured by wireless sensors and these values are related to distances between wireless receivers and transmitters. Transmitter power (P_{TX}) is related to received power (P_{RX}) at receiver. Friis' free space transmission model gives a formula to calculate received power.

$$P_{RX} = P_{TX}.G_{TX}.G_{RX}\left(\frac{\lambda}{4\pi D}\right)^2 \quad (1)$$

In this formula;

P_{TX} is transmitter power

P_{RX} is receiver power

G_{TX} is transmitter gain

G_{RX} is receiver gain

λ is wave length

D is distance from receiver

RSSI value is calculated by P_{RX} and P_{REF} values as:

$$RSSI = 10.\log\frac{P_{RX}}{P_{REF}} \text{ dBm} \quad (2)$$

P_{REF} is defined as the absolute value of P_{REF} = 1 mW.

RSSI values, received by the receiver, increase with the decreasing D distances. The relationship between RSSI and distance D can be expressed as

$$RSSI = A - 20.\log D \quad (3)$$

Where, A is the environmental constant

During RF signal transmissions, environmental affects degrades the quality of transmitted signals and in return decreases the amplitudes of RSS values. RSS is a measure of total energy of the received signal.

On the other hand, Link Quality indicator (LQI) is introduced to define the quality of signal packets received by the receiver. Signal to noise ratio (SNR) is another quantity to judge the signal quality. LQI is obtained by considering both the signal energy and SNR.

LQI defines several retransmissions between a transmitter and a receiver to receive one signal packet correctly by the receiver. Transmitters transmit signal packets continuously in a loop. A receiver receives these radio signal packets and forwards them in LQI format to a server PC.

It can be seen that LQI values of incoming RF signals decrease with increasing distances. Plots of Signal amplitudes versus distances are always reproducible between any transmitter and receiver pair. According to IEEE802.15.4 standards, LQI is an identification of RF signal strength and the quality of received signal packet. LQI is proportional to RSSI and signal-to-noise ratio estimation.

LQI value is calculated when a data frame is received based on signal strength. Wireless sensor node defines the signal strength by reading the sensor gain in order to receive the signal frame. This gain is converted into a range between 0 and 255 discrete levels identified as LQI values. 0 is the lowest and 255 is the highest LQI value. Conversion between LQI and RSSI values differs for different wireless sensor nodes. LQI values can also be utilized to localize the unknown objects in any test area.

III. FILTER THEORY

Signal processing is an important part of communication theory. Signals received in many ways are required to be cleaned from noise. There are various different noise types. One of them is environmental noise.

There are some filtering techniques to reduce the noise rate, Low Pass, High Pass, BandPass filtering are a few of them. Each filter is explained by a transfer function between its input and output in frequency domain. In filters, signals with a certain frequency range are allowed to pass and the rests are stopped. These are identified as pass band and stop band frequencies.

In Kalman Filtering [14,15], on the other hand, filtering is carried out by using a prediction mechanism. New values are corrected with respect to previous values. The state of filtering is estimated from previous state measurements which contain random errors. One-Dimensional Kalman filtering can be applied with RSSI or LQI values received with random variations. Operational diagram of Kalman filtering is shown in Fig. 1.

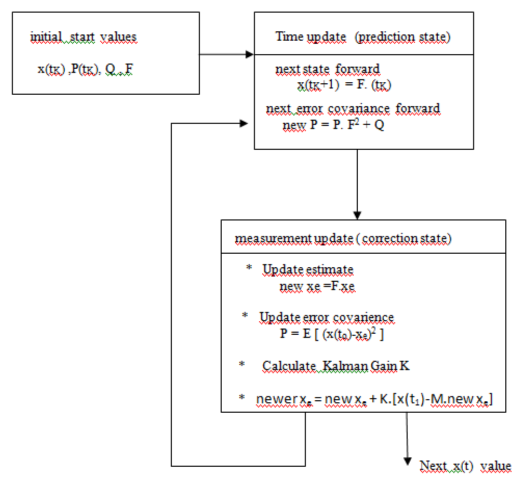

Fig. 1 Block diagram of Kalman filtering

Assume that x(t) is a random variable and if there is a need to calculate its value at different t times x(t), a linear relationship can be defined between x(t) and x(t+1).

$x(t_k+1)=F.(t_k) + u(_k)$

Where, F is a constant, u(k) is noise with zero mean and variance Q.

An initial estimate is necessary for Kalman Filtering to start. Initial estimate of x at t=0 is the actual value of x at start. $x(t_0)$ is defined as xe and x_e is the best estimate of x . The variance of error x_e bocomes

$$P = E[(x(t_0) - x_e)^2]$$

E is the operator ,$x(t_0)$ is x value at t_0.

next value $x(t_1)$ can be defined as

$$x(t_1) = x(t_0 + 1) = F.x(t_0) + u(0)$$

where k=0.

The new best estimate of $x(t_1)$ becomes :

$_N$ew $x_e = F.x_e$

Variance of error of this estimate is

$$newP = E[(x(t_1) - newx_e)^2]$$

Substitution results in newP value as

$$newP = E[(F^2.(x(t_0) - x_e)^2 + E.u^2 + 2E[F(x(t_0) - x_e).u]$$

There is no correlation between u and $x(t_0)$ and x_e . Hence Last term is zero. newP becomes

$$newP = P.F^2 + Q$$

By using numerical values for initial P,Q,F values ; newP can be calculated.

A new estimated xe value is calculated for each x value. This process continues for all the x values which are introduced in the system [16].

IV. Implementation

1 Dimentional Kalman filtering is applied on the recorded values of LQI values in a localization experiment. Jennic wireless sensor devices employed in indoors [11,12]. Wireless transmitters radiate RF transmission and they are recorded by wireless receivers in the form of LQI values. Receivers are connected to a server computer by a wireless Dlink connection and LQI values are recorded in an access database. There are 5 transmitters strategically placed in an indoor test area as shown in Figure 2..

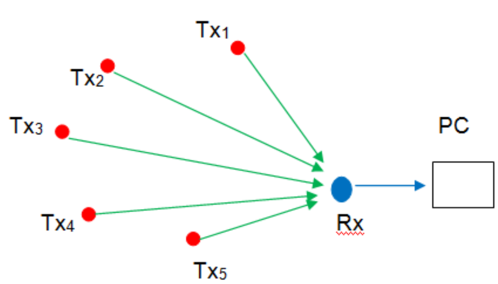

Fig. 2 Experimental set up across the test area.

105 LQI values are recorded from each transmitter. First 15 of them are displayed in Figure 3. Mean and STD values of these 15 LQI values for each transmitter are also calculated and displayed in Figure 3.

LQI recordings have random behavior due to environmental effects. These random behaviors will be corrected with Kalman filtering. Samples of unfiltered LQI recordings in Figure 3 are plotted in Figure 4 and 5 for readers inspection.

No.	LQI$_A$	LQI$_B$	LQI$_C$	LQI$_D$	LQI$_E$
1	186	172	102	114	84
2	186	174	100	110	78
3	78	104	98	106	74
4	78	100	96	82	68
5	78	96	36	54	100
6	118	64	60	100	196
7	138	168	72	98	64
8	138	170	96	96	54
9	90	54	106	96	90
10	90	90	102	98	80
11	76	174	84	100	72
12	78	172	78	174	82
13	94	82	78	172	54
14	110	54	72	100	72
15	72	168	66	98	74
MEAN	107,4	122,8	83,1	106,6	82,8
STD	37,3	47,4	19,1	29,3	32,5

Fig. 3 Sample of unfiltered LQI recordings from 5 transmitters

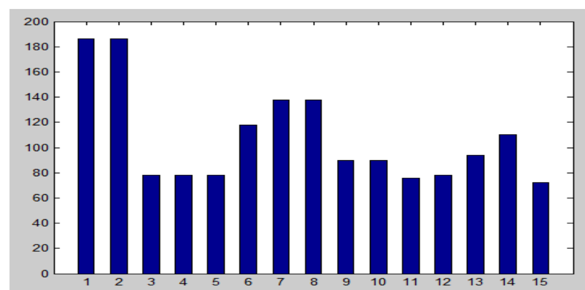

Fig. 4 unfiltered LQI recordings of transmitter A

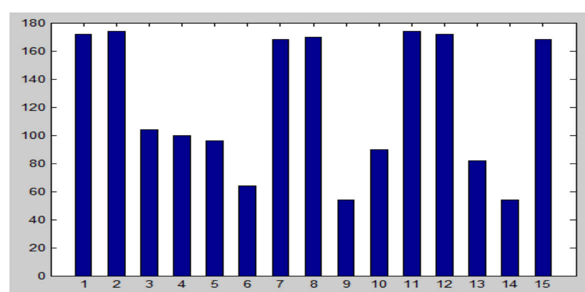

Fig. 5 unfiltered LQI recordings of transmitter B

A software program is developed to apply the one dimensional Kalman filtering on raw recorded LQI values to decrease the observed randomness among LQI values before any position estimation calculations. Algorithm of Kalman Filtering is listed as follows:

Begin:
1. Define initial parameters
2. Record LQI measurements $x(t_K)$
3. Define variance Q= e^{-3}
4. Make initial guesses
5. Make time update (prediction)
6. Make measurement update (correction)
7. Calculate new LQI values
8. Plot filtered LQIs against their coordinates

End

Random LQI values in an array are taken in stream form as input by the program and they are Kalman Filtered out again in stream form as output. Some examples of filtered and none filtered LQI data are given in Figure 6to 8.

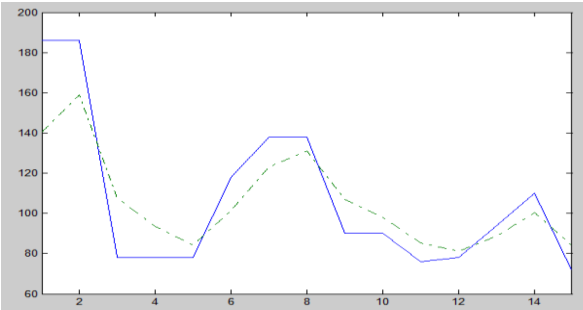

Fig. 6 Filtered and unfiltered LQI values for transmitter A
Dotted line is kalman filtered output for first 15 LQI values

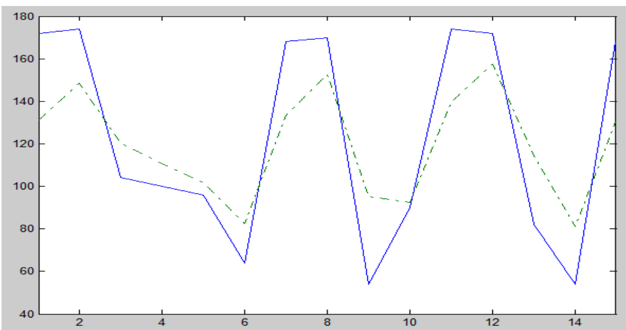

Fig.7 Filtered and unfiltered LQI values for transmitter B
Dotted line is Kalman filtered output for first 15 LQI values

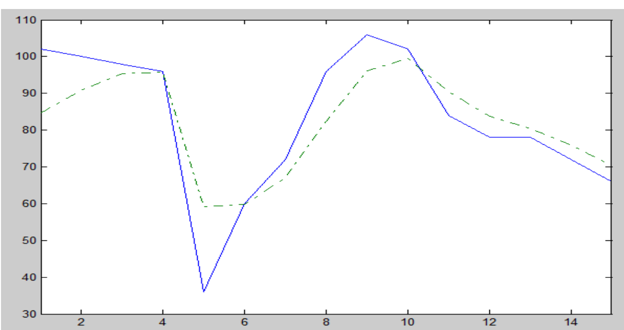

Fig.8 Filtered and unfiltered LQI values for transmitter C
Dotted line is Kalman filtered output for first 15 LQI values

105 unfiltered LQI recordings corresponding to each transmitter are divided in to 7 groups. Each group has 15 LQI values. Mean and STD values are calculated for each group of unfiltered LQI values. They are presented for transmitters A and B in Figure 9.

A	**1-15**	**16-30**	**31-45**	**46-60**	**61-75**	**76-90**	**91-105**
Mean	107,4	70,8	89,8	84,4	75,5	67,1	49,2
STD	37,3	21,7	28,3	10,8	20,6	29,7	28,3
B	**1-15**	**16-30**	**31-45**	**46-60**	**61-75**	**76-90**	**91-105**
Mean	122,8	83,6	100,2	87	88,5	89,4	93,5
STD	47,4	19,6	19,1	18,9	17,1	18,5	17,4

Fig.9 Mean and STD values of un**filtered** LQI values in 7 groups for A and B transmitters

Similarly, Mean and STD values are calculated for each group of filtered LQI values. They are presented for transmitters A and B in Figure 10.

A	**1-15**	**16-**	**31-**	**46-**	**61-**	**76-**	**91-**
Mean	96,4	65,3	83,5	77,7	69,3	64,3	49,2
STD	24,2	16,7	15,8	8	16,6	20,1	28,3
B	**1-15**	**16-**	**31-**	**46-**	**61-**	**76-**	**91-**
Mean	110,7	78,3	92,1	79,3	80,9	82,2	93,5
STD	25,8	14,8	11,7	12,4	11,3	14	17,4

Fig.10 Mean and STD values of **filtered** LQI values in 7 groups for A and B transmitters

Distribution of Filtered and unfiltered Mean and STD values are presented graphically in Figures 11 to 14 for transmitters A, B.

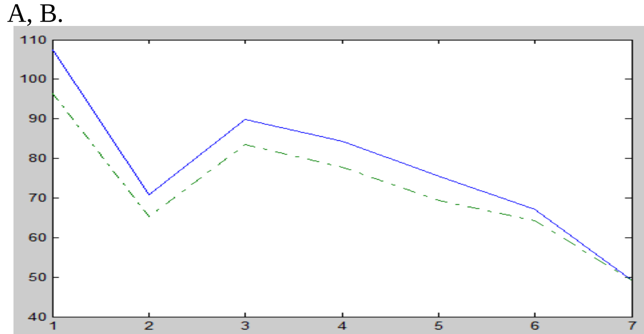

Fig.11 Distribution of LQI mean values for transmitter A.
Dotted line is filtered LQI means

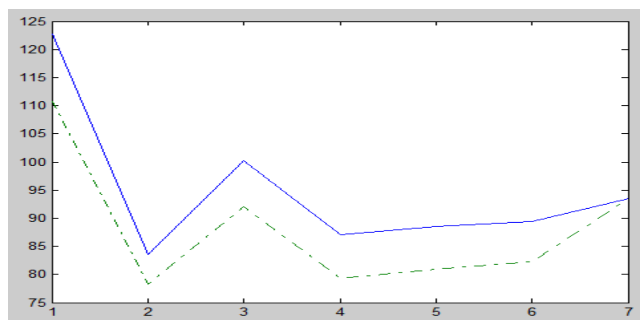

Fig.12 Distribution of LQI mean values for transmitter B.
Dotted line is filtered LQI means

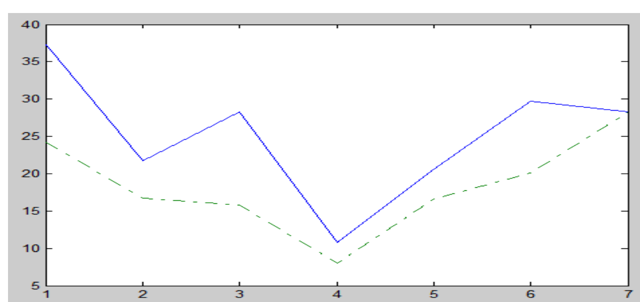

Fig.13 Distribution of LQI STD values for transmitter A.
Dotted line is filtered LQI STDs.

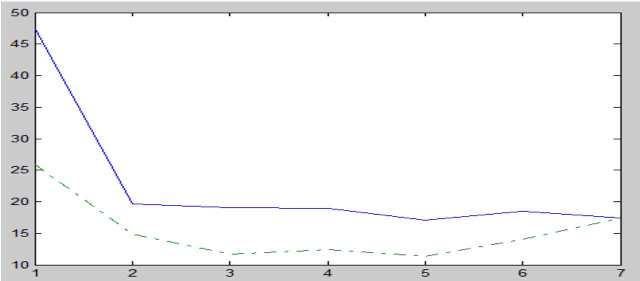

Fig.14 Distribution of LQI STD values for transmitter B. Dotted line is filtered LQI STDs.

Average mean and STD values of unfiltered and filtered mean and STD values in 7 groups for each transmitter are presented in Figure 15. It can be observed that Kalman filtering reduces the randomness of LQI values by reducing their mean and STD values. An average 7% reduction in Mean and around 30% reduction in STD values are recorded. Hence, variations of LQI values in the range of Mean ± STD are decreased by reducing the mean value and the STD range around this mean. Resultant position determinations become more accurate.

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unfiltered	**A**	**B**	**C**	**D**	**E**
mean avg.	77,7	95	94	97,3	85,6
STD avg.	25,2	22,6	22	31,2	26,2
filtered	**A**	**B**	**C**	**D**	**E**
mean avg.	72,2	88,1	87,9	90,3	80,6
STD avg.	18,5	15,3	17,9	23,8	18,4

Fig.15 Average Mean and STD values of filtered and unfiltered mean and STD values for all the transmitters

V. CONCLUSIONS

Kalman Filtering is one of the best ways of reducing random behavior of signals in real time. The technique uses a prediction method to determine present quantities from past values. In this study , LQI amplitudes are recorded from transmitters at various locations. These LQI values are utilized to determine the unknown object locations. The results show that the random fluctuations among the LQI values are reduced and better LQI distribution is obtained. Secondly, the recorded LQI values from each transmitter are grouped and their mean and STD values are calculated. Kalman filtering is applied on these Mean and STD values among groups. The results show a high level of reduction in random values. These smoothed Mean and STD values are utilized to produce a range of LQI values such as Mean ±STD for each transmitter . These new LQI values are used in localization compare to those LQI values in the ranges of raw LQI values. The results show better accuracies.

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