LTE-CommSense System and its Feasibility Analysis

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***Abstract*—This paper describes a novel way to use the existing communication infrastructure of LTE (Long Term Evolution) to monitor the change in the environment along with its feasibility analysis. This system is named LTE-CommSense by the authors and can be used in many environment sensing objectives namely monitoring of crop growth over a period of time, disaster monitoring, sea state monitoring, snow avalanche monitoring, security of large unmanned landscapes etc. This technology focuses on already known information from received signal e.g. reference symbols in the LTE communication signal frames. In the equalizer block of the receiver, the equalizer tap coefficients gets modified while training the equalizer using reference symbols. These modifications depend on the channel through which the received signal has passed through. Therefore the adaptive equalizer tap coefficients contain information related to the channel condition. We propose to use these coefficients to get an estimate of change in the channel properties. LTE spectrum and infrastructure will be utilized to get channel characteristics without affecting the existing communication system. After the channel information is received, phenomenological knowledge about the environment will be obtained using ASIN (Application Specific INstrumentation) phylosophy. We present a feasibility analysis of the novel scheme in this paper. We used LTE specific channel models from ITU (International Telecommunication Union) with AWGN noise as the dataset and nearest neighbour based classifier to validate this scheme.**

***keywords* - LTE, LTE-CommSense, adaptive equalizer, ASIN, ITU.**

I. INTRODUCTION

The first study of using Radar systems for limited amount of data communication is the US patent published in the year 1969 by Ritterbach [1]. Recently, there also has come an upsurge in activities in the field of using communication radiation for target detection and tracking using receiver only nodes. This field popularly known as passive Radar or commensal Radar ([2], [3]).

The coexistence of communication and radar systems can be broadly categorized into three types (inspired by biological inter-species coexistence): commensal systems (one system exploits other without detrimental effect), symbiotic Systems (systems coexist and benefit from existence of each other e.g. Ritterbach patent [1], Moon-Sik patent [4] & Whitespace Radar [5]) and parasitic systems (one system affects the other in detrimental manner e.g. electronic defence & electronic warfare systems).

The proposed work uses a novel commensal radar system, called CommSense [6], [7], and it uses LTE communication infrastructure. Therefore, we call this system LTE-CommSense. LTE communication system is chosen as a communication platform in the CommSense phylosophy because it is widely spread now a days. Also, utilization of orthogonal frequency division multipleing (OFDM) and multiple input & multiple output (MIMO) may provide better resolution for our scenario compared to previous communication standards. The novelties of this proposed system are two fold. First of all, it builds upon existing communication system to monitor the environment. This is different from any classic radar system which mainly cater to measuring the range and Doppler of a target in the scene. Secondly, and this is the major novelty of the work, LTE-CommSense does not perform correlation based processing like most existing commensal radar systems. Instead it uses the reference signal in the received communication signal to estimate the fading channels and there by predict the change in the environment.

In this paper we will show that, this is possible within practicalities of simulation and we can recognise different kinds of channels by using the channel estimation and equalization blocks of LTE. LTE specific six different channel models according to ITU guidelines, namely Pedestrian A (PA), Pedestrian B (PB), Vehicular A (VA), Extended Pedestrian A (EPA), Extended Vehicular A (EVA) amd Extended Typical Urban (ETU) are used for this analysis. The training and recognition datasets contain multiple readings for each of these channel models each having different amount of AWGN noise added to it. Naive nearest neighbour based classifier is used to classify the recognition dataset using the training dataset as reference. The results shows promising performance of this novel scheme.

This paper is organized in the following manner. Section II explains the basic concept of CommSense. The feasibility analysis results of our proposed scheme is detailed in section III and conclusion & future work is provided in section IV.

II. THE CONCEPT OF COMMSENSE

In a communication system, the major thrust is on correctly estimating the received signal at the receiver. The communication channel in between the base station and the receiver is mostly assumed to be known. Whereas in a Radar system, the channel is what we try to estimate. Communication systems use a range of processes and algorithms to get a real-time estimate of fading and non-ergodic channels and then try to

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filter out the effect of the same. Hence, the aim of CommSense will be to estimate the noise for communication systems.

Most modern communication standards and the adhering equipments cater for dynamic channel estimation. These schemes use known pilot signals in the received burst to estimate the channel and then filter the channel modulations out. Depending on these observations, CommSense or Communication based Sensing system is proposed here. This system will perform the following.

1) estimate the channel properties using the communication signal which is transmitted from communication baase station and received by communication receiver, and
2) make a prediction regarding the change in the surrounding environment based on the variation in the channel properties.

The information collected should be properly mapped from the measurements to physical events in the environment. This type of phenomenological knowledge extraction is a challenging work even in conventional radar systems also [8]. To resolve this issue, different stages in the processing chain of the proposed LTE-CommSense system is shown in Figure 1. There are two sets of input and hence processing-chains in the system. The first one is a real-time system input coming from the UEs in the field. The second chain of information and processing is set by the mission control and depends on the purpose to which the LTE-CommSense will be put to for a particular time frame.

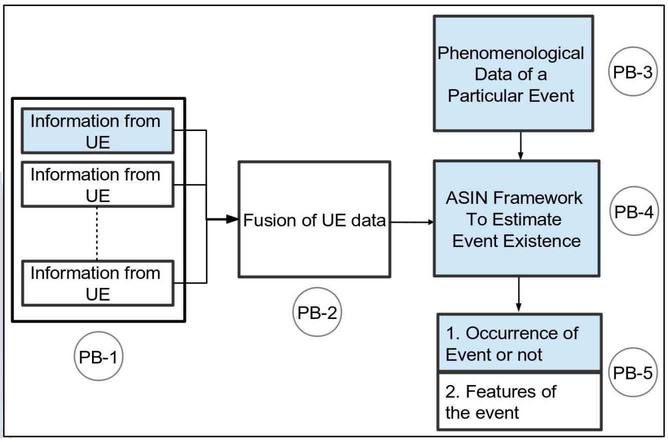

Fig. 1. LTE-CommSense system: Building blocks and data-processing flow

A short description of each of the process-block (PB) are given below:

Process-block 1: Extracts information from channel equalization, done using adaptive filtering technique. In future, multiple UEs will be used to cover wider area. In that case, the adapted filter coefficients of the UE will be sent to process-block 2.

Process-block 2: Fuses all the information collected from UEs of PB-1. In this analysis single UE is considered and therefore PB-2 is bypassed.

Process-block 3: Gathers information about the event that need to be detected. This is used to train the ASIN block in PB-4.

Process-block 4: Trains and uses an ASIN block. ASIN is a pattern classification system which trains itself using the information from PB-3 and then gives prediction in real-time using information from PB-1 & PB-2.

Process-block 5: Delivers information from PB-4 to user. This information will consist of event occurrence confirmation and/or details of the event (if the event has occurred).

Phenomenological knowledge regarding the environment will be obtained by utilizing bio-inspired ASIN framework [9], [10], shown in the figure. ASIN tries to estimate one or a few anomalies only instead of trying to estimate everything in the scene. Depending on what use a particular LTE-CommSense will be put into, a set of field trials will be run to gather information about the anomaly to detect and characterize. Then it can sense and characterize when that particular kind of occurrence happens in the environment. The output of the system will consist of two sets of information. First, it gives a likelihood of a particular event occurring. Secondly, given that the likelihood of that even is high enough, it gives some basic characteristics of the event also.

The proposed method will be demonstrated in indoor/outdoor environment by implementing LTE communication standard in GNURadio environment along with a software radio platform (SDR) platform. Information regarding environment changes will be extracted from very less amount of observation. Therefore, it is proposed to measure the channel from as many different locations as possible using multiple cooperative UEs. Each UE will transmit their GPS position along with the filter coefficients values. But in this initial feasibility analysis, we have considered a singe UE.

The scene of interest depends on the range of the UEs. For LTE, scene size will keep on changing and mostly will be confined to as small as the pico-cell sizes. Also, in case a LTE-CommSense system for constant monitoring of a certain area of interest, fixed UEs can be installed. The cost of such a system will be low as these will be receiver-only devices.

In LTE-CommSense, CommSense infrastructure will utilize existing LTE communication standard. The specifications for LTE was standardized in the form of Rel-8 and approved in January 2008. Target deployment started in 2010 [11]. The LTE requirements and LTE enabling technologies can be found in [12]. We are interested in LTE downlink reference signal [13] which we will use for channel estimation & equalization. In the LTE downlink, three different types of reference symbols (RSs) are provided: cell-specific RSs, UE-specific RSs and Multimedia Broadcast Single Frequency Network (MBSFN) specific RSs.

The LTE specifications don't mandate any specific channel estimation & equalization technique provided the performance requirements are met and complexity is affordable [13]. Channel estimation & equalization can be performed either in frequency domain (using channel transfer function (CTF) e.g. interpolation, least square (LS), regularized LS, minimum mean square error (MMSE), mismatched MMSE), time domain (using channel impulse response (CIR) e.g. MMSE, least mean square (LMS), normalized LMS, recursive least square (RLS), Kalman-based filtering) or in spatial domain (SD-MMSE). We will select an RS-aided channel estimation & equalization algorithm for our purpose.

III. Results & Feasibility Analysis

Six different ITU specified channel models for LTE channel analysis, namely Pedestrian A (PA), Pedestrian B (PB), Vehicular A (VA), Extended Pedestrian A (EPA), Extended Vehicular A (EVA), Extended Typical Urban (ETU) are used for our analysis. In Table I, we have shown the multi-path profile of these LTE channel models [13] .

In Figure 1, the highlighted processing blocks are implemented in the current feasibility analysis. In this present case, a single UE is used. Therefore, PB-2, which is required for fusion of data is irrelevant and not used here. Also, Determination of occurance of the event is analyzed here. The feasibility of extracting features of the detected event will be performed in the extended work in future.

The channel profile quantifies the delays and relative powers of the multi-path components. The multi-path components in the table are not uniformly spaced in the time domain. In channel equalization, the coefficients of the used adaptive filter is dependent on the delay profile of the channel. As the channel is time-varying, each filter tap will be updated using adaptive algorithm. Depending on the changes of these channel parameters, the adaptive filter coefficients will also change. This phenomena is utilized to extract information regarding corresponding changes in the channel. The filter is be modeled as an FIR (Finite Impulse Response) filter because we receive a finite number of delayed versions of original signal at UE. We considered LMS and MMSE channel equalization method for this study.

Now, we'll analyze the feasibility to determine environment change of a noisy channel using filter coefficients of the equalizer. First we will determine equalizer tap coefficients for different LTE channel models in various channel noise conditions. This information will be used to generate training and recognition dataset for the nearest neighbour classifier. The training dataset is developed using maximum 50 images of each CIR having different amount of AWGN noise. The testing dataset also created accordingly. Given a set of adaptive filter tap coefficients, the classifier determines, to which CIR in the training dataset it best corresponds.

The analysis is performed for different values of noise variance (σ). Three different noise variances are considered: 10, 5 and 0.1 respectively. For each noise variance, accuracy is calculated for different channel lengths and two different equalizers viz. MMSE and LMS to analyze the effect of filter length on the system performance. For the LMS filter, the learning parameter (μ) is taken to be 0.004. The nearest neighbour classifier uses L_1 distance (Manhattan Distance) for distinguishing the CIRs.

The classification performance is provided in terms of performance accuracy and confusion matrix. The accuracy is the percentage of correct classification. But from the confusion matrix, we can observe in which cases incorrect classification has occurred. In this case, confusion matrix will be a 6x6 square matrix wherein the diagonal elements corresponds to correct classification and off-diagonal elements corresponds to incorrect classification. Moreover, from the co-ordinates of these off-diagonal elements, we can determine, what is the original category of data and to what category it is classified. The recognition accuracy along with the confusion matrix for different noise variances are shown in table II, III and IV respectively.

Performance analysis of table II, III and IV proves that the idea of CommSense is feasible. Further, this limited study also showed that, MMSE is a better candidate for CommSense. For filter length more than 50, the performance accuracy of MMSE based system is consistent for the range noise condition considered. Therefore MMSE equalizer will be used in all our future experiments. Also, it can be seen that, the recognition performance improves with increase in the filter length. As the noise variance, The classification performance also increases.

TABLE II
FEASIBILITY ANALYSIS: CLASSIFICATION PERFORMANCE AT $\sigma = 10$

	LMS Equalizer based Method							MMSE Equalizer based Method						
Filter Length	Accuracy (%)	Confusion Matrix						Accuracy (%)	Confusion Matrix					
5	19.3333	13	15	5	2	9	6	35.3333	23	22	9	5	1	1
		8	7	7	10	12	6		11	15	8	8	7	1
		10	14	8	6	5	7		12	16	5	8	8	1
		5	13	8	7	8	9		5	4	6	13	20	2
		4	3	7	10	14	12		2	7	11	8	18	4
		4	13	4	10	10	9		0	3	1	5	9	32
50	51	48	0	2	0	0	0	86	26	0	24	0	0	0
		14	14	14	6	2	0		1	47	2	0	0	0
		28	11	10	1	0	0		10	2	35	0	3	0
		0	8	8	22	10	0		0	0	0	50	0	0
		0	7	0	12	27	4		0	0	0	0	50	0
		0	0	0	7	11	32		0	0	0	0	0	50
100	41	35	7	8	0	0	0	96.3333	45	2	3	0	0	0
		8	21	10	7	4	0		1	49	0	0	0	0
		15	14	14	4	3	0		4	0	45	0	1	0
		3	10	15	11	7	4		0	0	0	50	0	0
		1	8	5	14	16	6		0	0	0	0	50	0
		0	1	1	16	6	26		0	0	0	0	0	50

As a further analysis we compared the effect of 'measure of distance' used in the nearest neighbour classifier for distinguishing the CIRs. The results are shown in table V. Here, the filter length is fixed to be 50. The noise variance of 5.0 is considered. The learning parameter (μ) for the LMS filter is taken to be 0.004. It can be observed from the result that, Euclidian distance measure is more suitable for our purpose.

IV. Conclusion and Future Work

The work presented here, describes the feasibility of a novel development to the field of communication based environment sensing. It can be concluded from the analysis of the results discussed here that the proposed system is feasible in practice. CommSense being essentially a commensal radar, will not affect existing communication system in any way. Hence the

TABLE I
PROPAGATION CONDITIONS FOR MULTI-PATH FADING IN THE ITU MODELS USED FOR LTE

	Pedestrian A (PA)		Pedestrian B (PB)		Vehicular A (VA)		Extended Pedestrian A (EPA)		Extended Vehicular A (EVA)		Extended Typical Urban (ETU)	
Tap No.	Relative Delay (ns)	Relative Mean Power (db)	Relative Delay (ns)	Relative Mean Power (db)	Relative Delay (ns)	Relative Mean Power (db)	Relative Delay (ns)	Relative Mean Power (db)	Relative Delay (ns)	Relative Mean Power (db)	Relative Delay (ns)	Relative Mean Power (db)
1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	-1.0
2	110	-9.7	200	-0.9	310	-1.0	30	-1	30	-1.5	50	-1.0
3	190	-19.2	800	-4.9	710	-9.0	70	-2	150	-1.4	120	-1.0
4	410	-22.8	1200	-8.0	1090	-10.0	80	-3	310	-3.6	200	0.0
5	-	-	2300	-7.8	1730	-15.0	110	-8	370	-0.6	230	0.0
6	-	-	3700	-23.9	2510	-20.0	190	-17.2	710	-9.1	500	0.0
7	-	-	-	-	-	-	-	-	1090	-7	1600	-3.0
8	-	-	-	-	-	-	-	-	1730	-12	2300	-5.0
9	-	-	-	-	-	-	-	-	2510	-16.9	5000	-7.0

TABLE III
FEASIBILITY ANALYSIS: CLASSIFICATION PERFORMANCE AT $\sigma = 5$

	LMS Equalizer based Method							MMSE Equalizer based Method						
Filter Length	Accuracy (%)	Confusion Matrix						Accuracy (%)	Confusion Matrix					
5	46.3333	43	3	4	0	0	0	82.3333	50	0	0	0	0	0
		1	14	14	7	9	5		0	28	18	4	0	0
		6	11	28	4	1	0		0	18	32	0	0	0
		0	7	4	23	10	6		0	2	0	44	4	0
		0	6	2	13	12	17		0	0	0	3	46	1
		0	4	3	9	15	19		0	0	0	0	3	47
50	52.6667	41	1	7	0	1	0	99.3333	48	0	2	0	0	0
		5	28	17	0	0	0		0	50	0	0	0	0
		23	3	23	0	1	0		0	0	50	0	0	0
		3	0	0	47	0	0		0	0	0	50	0	0
		7	4	17	5	17	0		0	0	0	0	50	0
		9	8	15	9	7	2		0	0	0	0	0	50
100	45	50	0	0	0	0	0	100	50	0	0	0	0	0
		39	0	11	0	0	0		0	50	0	0	0	0
		44	0	6	0	0	0		0	0	50	0	0	0
		18	7	7	16	2	0		0	0	0	50	0	0
		0	2	2	26	20	0		0	0	0	0	50	0
		0	0	0	3	4	43		0	0	0	0	0	50

TABLE IV
FEASIBILITY ANALYSIS: CLASSIFICATION PERFORMANCE AT $\sigma = 0.1$

	LMS Equalizer based Method							MMSE Equalizer based Method						
Filter Length	Accuracy (%)	Confusion Matrix						Accuracy (%)	Confusion Matrix					
5	93.3333	50	0	0	0	0	0	100	50	0	0	0	0	0
		0	48	2	0	0	0		0	50	0	0	0	0
		0	1	49	0	0	0		0	0	50	0	0	0
		0	0	0	50	0	0		0	0	0	50	0	0
		0	0	0	0	44	6		0	0	0	0	50	0
		0	0	0	0	11	39		0	0	0	0	0	50
50	99.3333	50	0	0	0	0	0	100	50	0	0	0	0	0
		0	50	0	0	0	0		0	50	0	0	0	0
		0	0	50	0	0	0		0	0	50	0	0	0
		0	0	0	50	0	0		0	0	0	50	0	0
		0	0	0	0	50	0		0	0	0	0	50	0
		0	0	1	0	1	48		0	0	0	0	0	50
100	96	50	0	0	0	0	0	100	50	0	0	0	0	0
		0	50	0	0	0	0		0	50	0	0	0	0
		0	0	50	0	0	0		0	0	50	0	0	0
		0	0	0	50	0	0		0	0	0	50	0	0
		0	1	2	0	47	0		0	0	0	0	50	0
		0	0	0	1	8	41		0	0	0	0	0	50

required effort will be less and also it'll be a cost effective solution. Proposed LTE-CommSense will be utilized to detect & characterize environment changes. In the next phase, this feasibility analysis will be extended for the case of multiple input multiple output (MIMO) scenarios, compatible with LTE standard. Then, the proposed LTE-CommSense system will be implemented using an SDR environment and validated in both laboratory (restricted/indoor) & outdoor environment.

TABLE V
EFFECT OF DISTANCE MEASURE ON THE CLASSIFIER PERFORMANCE

	LMS Equalizer based Method							MMSE Equalizer based Method						
Measure of distance	Accuracy (%)	Confusion Matrix						Accuracy (%)	Confusion Matrix					
L_1 (Manhattan)	52.6667	41	1	7	0	1	0	99.3333	48	0	2	0	0	0
		5	28	17	0	0	0		0	50	0	0	0	0
		23	3	23	0	1	0		0	0	50	0	0	0
		3	0	0	47	0	0		0	0	0	50	0	0
		7	4	17	5	17	0		0	0	0	0	50	0
		9	8	15	9	7	2		0	0	0	0	0	50
L_2 (Euclidian)	57.6667	44	0	4	2	0	0	99.6667	49	0	1	0	0	0
		6	38	5	1	0	0		0	50	0	0	0	0
		22	11	15	1	1	0		0	0	50	0	0	0
		1	0	0	49	0	0		0	0	0	50	0	0
		9	6	10	3	20	2		0	0	0	0	50	0
		3	5	17	10	8	7		0	0	0	0	0	50

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