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Review of IEEE 802.15.4 for Intelligent Transport System Application

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Abstract- These days, mass-produced vehicles benefit from research on Intelligent Transportation System (ITS). One prime example of ITS is vehicle Cruise Control (CC), which allows it to maintain a pre-defined reference speed, or to focus all of the driver's attention on the steering of the vehicle. However, achieving efficient Cruise Control is not easy in roads or urban streets where sudden changes of the speed limit can happen, due to the presence of unexpected obstacles or maintenance work, causing, in inattentive drivers, traffic accidents. In this communication we present a new Infrastructure to Vehicles (I2V) communication and control system for intelligent speed control, which is based upon Zigbee technology for identification of traffic signals on the road, and high accuracy vehicle speed measurement with a Hall effect-based sensor. The efficient adaptation of the speed of the vehicle to the circumstances of the road. The performance of the system is checked empirically, with promising results.

This paper proposes the modification of current market products and proposals of Zigbee system to make it suitable for vehicular communication system to route post-accident warning messages up to an effective NLOS distance in a co-operative manner. In a vehicular communication system, routing of warning messages in a co-operative manner increases vehicle safety and reduces mass crash, unexpected traffic jams after a crash and similar other incidents. It enables transmission of important data to the vehicles within an effective non-line-of-sight (NLOS) distance. We also show the simulated bit error rate (BER) results and co-operative routing distances for different vehicles in two scenarios. BER for both of the line-of-sight (LOS) and NLOS cases are calculated in the simulation.

Keywords— RFID, Vehicular Communication System, V2V, V2R, Co-operative Routing.

INTRODUCTION

A recent study by the UK Government's Office of Science and Innovation, which examined how future intelligent infrastructure would evolve to support transportation over the next 50 years looked at a range of new technologies, systems and services that may emerge over that period. One key class of technology that was identified as having a significant role in delivering future intelligence to the transport sector were wireless sensor networks and in particular the fusion of fixed and mobile networks to help deliver a safe, sustainable and robust future transport system based on the better collection of data, its processing and dissemination and the intelligent use of the data in a fully connected environment. As future intelligent infrastructure will bring together and connect individuals, vehicles and infrastructure through wireless communications, it is critical that robust communication protocols are developed. Mobile Ad-hoc Networks (MANETs) are self organizing mobile networks where nodes exchange data without the need for an underlying infrastructure.

In the road transport domain, schemes which are fully infrastructure-less and those which use a combination of fixed (infrastructure) devices and mobile devices fitted to vehicles and other moving objects are of significant interest to the ITS community as they have the potential to deliver a 'connected environment' where individuals, vehicles and infrastructure can co-exist and cooperate, thus delivering more knowledge about the transport environment, the state of the network and who indeed is travelling or wishes to travel. This may offer benefits in terms of real-time management, optimization of transport systems, intelligent design and the use of such systems for innovative road charging and possibly carbon trading schemes as well as through the CVHS (Cooperative Vehicle and Highway Systems) for safety and control applications. Within the vehicle, the devices may provide wireless connection to various Information and Communications Technologies (ICT) components in the vehicle and connect with sensors and other nodes within the engine management system.

There is growing consumer demand for wireless communication technologies in transport applications from point-to-point to multiplexed communications. Advances in portable devices (mobile phone, personal digital assistant and GSM devices) may exploit the possibility of interconnection using in vehicle communications. Also advances in wireless sensor networking techniques which offer tiny, low power and MEMS (Micro Electro Mechanical Systems) integrated devices for sensing and networking will exploit the possibility of vehicle to vehicle and vehicle to infrastructure communications. The important innovations in wireless and digital electronics will support many applications in the areas of safety, environmental and emissions control, comfort and entertainment, driving assistance, diagnostics and maintenance in the transport domain.

I. ZIGBEE

The ZigBee standard [9] has evolved since its original release in 2004 and it is a new low cost low power wireless networking standard for sensors and control devices. ZigBee provides network speeds of up to 250kbps and is expected to be largely used in wireless sensor network applications where high data rates are not required. ZigBee uses the

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media access control layer and physical layer of IEEE 802.15.4 for communication between devices. ZigBee offers a short range wireless networking capability with low cost, low data rate and low power consumption.

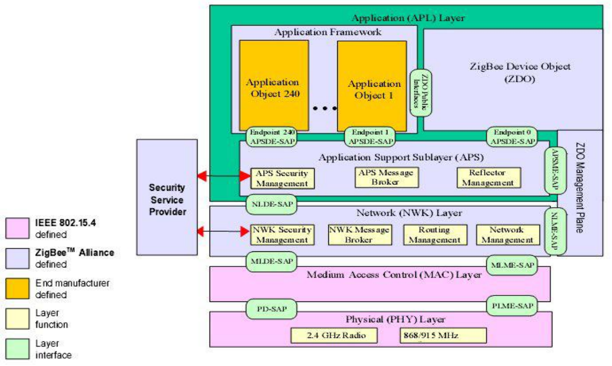


Figure 1 shows the ZigBee stack architecture which is made up of blocks called layers.

Each layer performs specific functions in the ZigBee protocol architecture. A data entity provides a data transmission service and a management entity provides all other services. Each service entity exposes an interface to the upper layer through a service access point (SAP) and each SAP supports a number of service primitives to achieve the required functionality

The IEEE 802.15.4 standard defines the two lower layers which are the physical layer (PHY) and the medium access control layer (MAC). The ZigBee protocol builds upon on this foundation by providing the network layer (NWK) and the framework for the application layer. The application layer framework consists of the application support sub-layer (APS) and the ZigBee device objects (ZDO). IEEE 802.15.4 has two PHY layers that operate in two separate frequencies: 868/915 MHz and 2.4 GHz. The lower frequency PHY layer covers both the 868MHz European band and the 915 MHz band, used in United States and Australia. The higher frequency PHY layer is used virtually worldwide. The IEEE 802.15.4 MAC sub-layer controls access to the radio channel using a CSMA-CA mechanism. Its responsibilities may also include transmitting beacon frames, synchronization and providing a reliable transmission mechanism.

The ZigBee network layer supports star, tree and mesh network topologies. The ZigBee coordinator is responsible for initiating and maintaining the devices on the star network topology. A star network topology is controlled by the coordinator and all other devices directly communicate with the coordinator. In the mesh and tree network topologies, the ZigBee coordinator is responsible for starting the network and for choosing certain key network parameters. In tree networks, routers move data and control messages through the network using hierarchical routing strategy.

ZigBee employs carrier sense multiple access (CSMA) as its protocol. The advantages that ZigBee derives through CSMA adoption is the reduced current drain, longer battery life elimination of waiting time for polling. ZigBee has been developed to suit the sensor and control applications. Basically, ZigBee shall cater to wireless personal area network (WPAN) applications that cover short distance communication and control requiring low data rates. A prime propelling factor promoting the ZigBee cause is the significant reduction in power consumption provided by this wireless standard which thereby facilitates in improving the battery life from hours to months and even to years. ZigBee technology has therefore evolved as an innovative standard for a market that stands highly fragmented today by the presence of a multitude of proprietary solutions creating numerous inter-operability issues. Its simplified implementation combined with the very low power consumption and limited cost of implementation shall drive the early adoption and acceptance of the standard. The active development of ZigBee chipsets and complete solution development by various companies globally stand witness to the expected boom of the ZigBee standard in the very near future in several applications including ITS.

II. SYSTEM SCHEMATIC AND SPECIFICATION

The system described in the following sections of the paper offers a unique and integrated solution to all the issues related to existing system and also has potential for future applications. In this system, we have proposed the use of ZigBee modules for traffic management and surveillance. ZigBee is a technology based on wireless protocol defined by IEEE 802.15.4 that offers a number of wireless sensor network applications. It has the advantages of having low power consumption, low cost, multiple topology support, self-routing and fault-tolerant networking, etc. Hence, it is particularly suited for our application discussed below.

- This proposed system comprises of ZigBee modules, one installed inside the vehicle, which will be directly interfaced with the ECU (Electronic Control Unit) and the other that will be installed at checkpoints placed at regular intervals alongside the road.
- The ZigBee module inside the car will acquire the data collected by the sensors preinstalled in the vehicle viz. instantaneous speed, engine-emission, seat-belt fastened status, etc. and broadcast the same wirelessly.

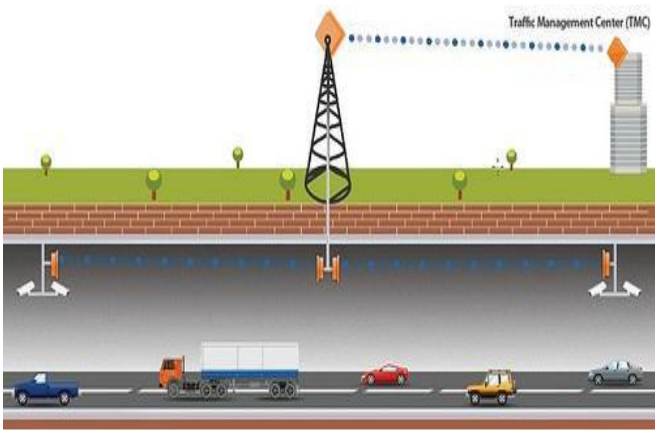


Figure 2: System Overview

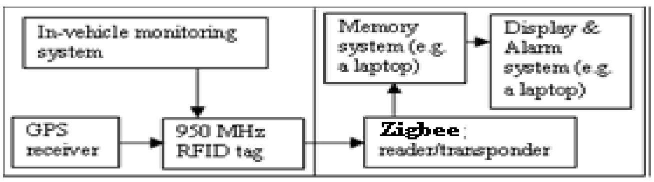
- Since the ZigBee module has a limited range, the broadcasted information packet from vehicle is received by

the checkpoint module only when the travelling vehicle comes in the range of the checkpoint zigbee. The checkpoint zigbee receives the broadcast packets and saves it into memory of MCU interfaced with it. In case of multiple cars coming across the checkpoint simultaneously the zigbee accepts packets from all
vehicles using sorting algorithm. The sorting algorithm ensures that the information of one car doesn't mix with the other. The information is then routed through other checkpoint zigbee station to the base station. The base station then forwards the information to central traffic control room where the information is queried and processed to form a database consisting of records of every vehicle.

III. SYSTEM DESIGN

A. OBU System Model

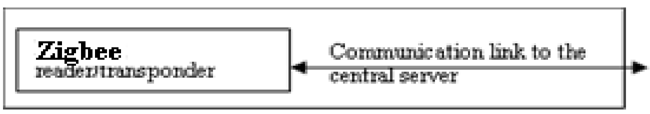
For V2V communication, each vehicle is equipped with an active 950 MHz RFID tag along with a tag reader/repeater interfaced with the in-vehicle storage and display system. The tag is connected to the GPS module to transmit positional value of the vehicle. At the same time, the tag is also interfaced with the in-vehicle monitoring system (IVMS). This interface should be able to instruct the tag to transmit a warning code relevant to any particular warning situation and the tag should be able to transmit data whenever there are data to be sent. The whole system for an OBU is shown in Fig. 3.



The interface along with the tag or IVMS is not shown as a separate module as it is assumed that it is embedded in either a tag or an IVMS. The interface is a major feature of the OBU in the proposed system. It is also assumed that the interface can be produced by the tag manufacturers or IVMS designers. Use of both the tag and the reader in the OBU is to make room for future extension of the proposed system for applications such as vehicle security (anti-theft measure), login to some access points etc. which are under investigation.

B. RSU System Model

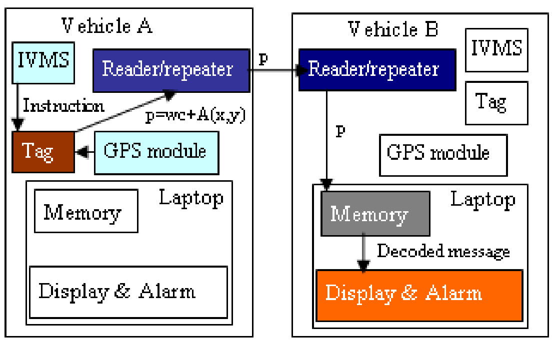
For R2V communication, the RSU contains only the tag reader/repeater and it is connected to the central server. The connection provides a way for central database management. This link is to be suitable for both-way communication. The system model for the RSU is shown in Fig. 4



In this system, we shall classify the zigbee modules being used as 'Vehicle Modules' (those installed in the vehicle) and 'Checkpoint Modules' (those installed at checkpoints on the road). As discussed above, it is necessary to have a coordinator to initiate any network. So for this system, the most optimum configuration is for all the Checkpoint modules to be configured as coordinators and all vehicle modules to be configured as Router/End device. Assigning of these two roles to the Zigbee modules is done by uploading the corresponding firmware using the proprietary softwares made available by the manufacturer. Also, ZigBee Network formation is governed by the SC (Scan Channels), ID (PAN ID), SD (Scan Duration), and NJ (Node Join Time) commands. Therefore these are common settings that must be configured on both vehicle- and checkpoint-modules. Having been configured with the above settings, the Zigbee modules are now ready for installation in the vehicle/checkpoint as per the individual role assigned to each one.
Now since it is not viable to design a separate interface for zigbee with each and every sensor in vehicle, it will be much better if a interface with ECU is established. Therefore it is prerequisite for the manufacturers of vehicle to provide interface of zigbee with ECU. The ECU should be programmed to provide required sensor information to the zigbee.

C.Vehicle and Pedestrian Information Flow for Avoiding Accident

Pedestrian information flow at intersection point is already defined and described in . So, for this option, pedestrians should carry tags and LF signal generators should be present in the roadside to activate pedestrian's tags. But the proposed system is also targeted to transmit the vehicles' warning messages when they are taking turn. So, tag in a vehicle transmits a warning message when the IVMS senses a turn taking activity in the vehicle. The message consists of a warning code and the positional data of the transmitter. The warning code is actually a short code which represents the warning information to be displayed on the display, such as 'a left turn is being taken' or 'a hard brake situation is happened'etc.
Fig.4 shows the flow of information for the V2V communication.



D. Information Flow in Post-Accident Message Routing.

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Post-accident warning message routing is proposed in this proposed system to avoid a mass crash which may occur due to hard brake or a sudden track change and such other activities from the first vehicle observing an accident in its front. In such a case the vehicles following the first observer vehicle may not be aware of its abnormal actions. The flow of information in this case is the same as the one shown in Fig. Just the warning code should be relevant to the situation. An IVMS is assumed to be capable of sensing all these situations. It is to be noted that in post-accident case, the first observer vehicle routes the accident information as well as its own abnormal actions (e.g. sudden brake or track change). Again, for suitable IVMS device, the crashed vehicle may also transmit warning messages.

V. SCENARIOS AND PARAMETERS FOR SIMULATION

A.Scenario Files for the Simulation

Three different scenarios are used for the emulation purposes. Scenarios are generated by the important framework. The simulation model and the scenarios are demonstrated below:

1. Scenario-1*:* In scenario-1, there are 15 vehicles along a road with 4 turns (4 phases). A phase is a straight road without any turn. The road forms a rectangular structure and only one turn is possible from a phase. In all cases, right turn is allowed in any direction along the road. There is only one lane in the road. In a lane, a vehicle moves towards a particular direction. The road is a closed loop and it does not affect this paper's simulation work as it is only for a small portion of the whole time of vehicle movement in the scenario. Fig. 5 shows the road of scenario-1. The whole area of the scenario is 1000 m × 1000 m. Each of the phases is 10 m wide. The inner rectangle shows an open space with 980 m × 980 m area. Vehicles are represented by black circles within a rectangle.
2. Scenario-2: There are 30 vehicles along almost the same road structure with 4 turns for 4 phases. This road also forms a rectangular structure. But there are two lanes in the road. In the two lanes, vehicles move opposite to each other and a vehicle cannot change a lane. Fig. shows the road of scenario-2. The whole area of the scenario is 1000 m × 1000 m. Each of the lanes is 10 m wide. The inner rectangle shows an open space with 960 m × 960 m area.

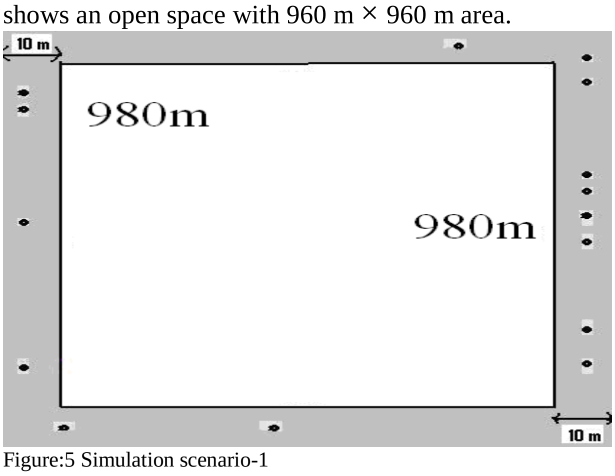

Figure:5 Simulation scenario-1

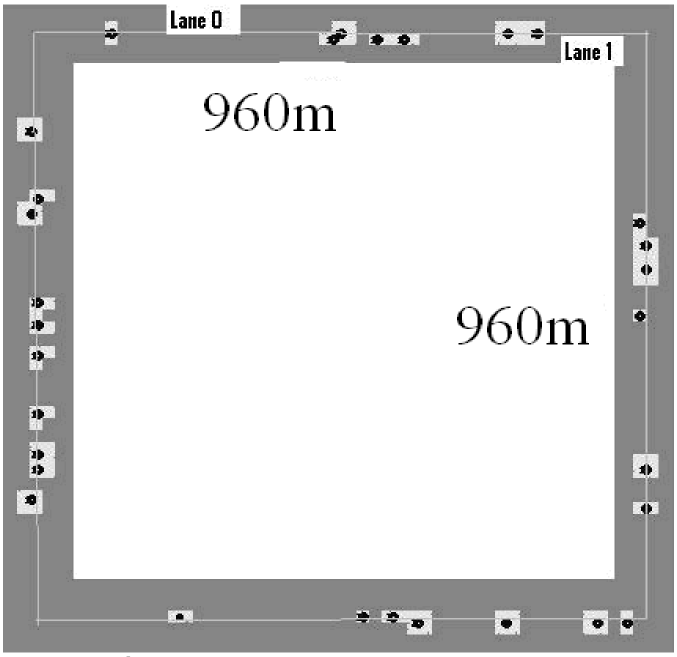

Figure 6:Simulation scenario-2

VI. RESULTS AND DISCUSSIONS

In the result, the cumulative BER means the BER for the last vehicle that takes part in the co-operative routing of the warning message. It is considered here that the received bits are redirected by each vehicle without any change. The BER values and the co-operative distances calculated here gives an average of the BER and co-operative distance values for six consecutive transmissions of 50000 random bits at an interval of 100 μs. The six samples are considered as enough for the averaging. For more samples simulation time may become too high. The results in the simulation may vary for the transmission of higher bits. 50000 bits are used in the simulation as lower amount of bits in transmission may cause insufficient BER results in some links. Average SNR and average BER are taken to get the average value of the performance. It is assumed that taking average does not lead to an error as the average SNR vs. average BER values match the theoretical values. Here the term 'co-operative distance' for a particular vehicle refers to the distance covered by the co-operative routing of a warning message generated by that vehicle. Cooperative distance 0 means there are no neighboring vehicles (vehicles within 150 m distance) for the transmitting vehicle. So, for the vehicles with nonzero co-operative distance, if the intermediate vehicle pairs possess a shorter inter-vehicle distance (< 100 m), their links face lower SNRs. But if any of these pairs possesses a longer distance (near 150 m or higher), SNR is higher. This is due to high attenuation of message signal at high distance. The followings are the simulation results for the two scenarios:

A.BERs and Co-operative Distances for Scenario-1

In scenario-1, the average co-operative distance for LOS case shows that the highest average co-operative distance is 262.95 m where 6 vehicles takes part in co-operative routing. Fig. shows the co-operative distances for LOS links in scenario-1.

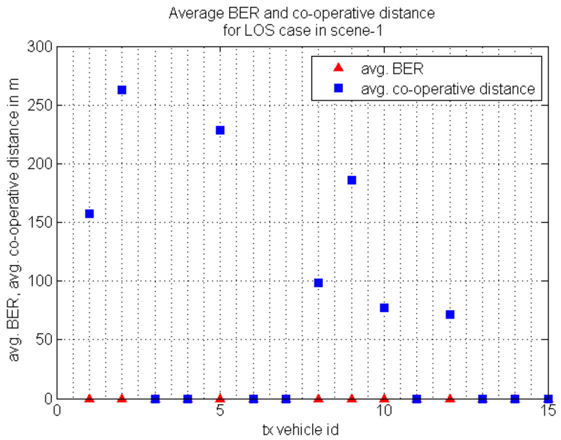

Figure 7: Average BER and co-operative distance results for LOS case in scenario-1

The LOS co-operative links for message transmission arefound for vehicles 1,2,5,8,9,10 and 12. The BER results show that there are enough intermediate SNRs for all cases to produce any BER for the current amount of bits transmitted in the simulation. Again for NLOS case, the average co-operative distance for vehicle 5 is 145.65 m which is better than the other cooperative distances. The average BER for this vehicle is 0.025.

Fig. shows the co-operative distances and BERs for NLOS links of the scenario-1. It is seen that the other average BER values are less than 0.025.

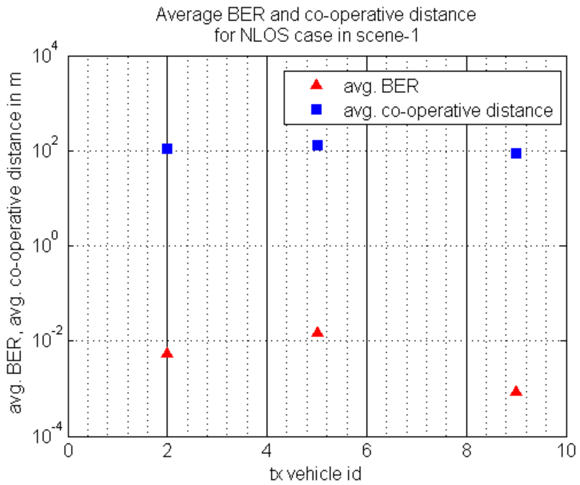

Figure 8: Average BER and co-operative distance results for NLOS case in scenario-1

For scenario-2, the co-operative distance for the vehicle 1 which is 535.74 m is more than those of the other vehicles. 10 vehicles participated in this co-operative routing. Fig. shows the co-operative distances and BER results for all LOS links in scenario-2. In this case, the BER values do not exceed 2e-5. The maximum co-operative distance calculated for NLOS case of scenario-2 is 392.15 m where vehicle 28 is the transmitter. There are 4 vehicles participating in this cooperative routing. The average cumulative BER is 0.044 for the 50000 bits of transmission in the simulation. Fig. shows the co-operative distances and BERs for NLOS links of the scenario-2. The other BER values are lower than the BER of vehicle 28.

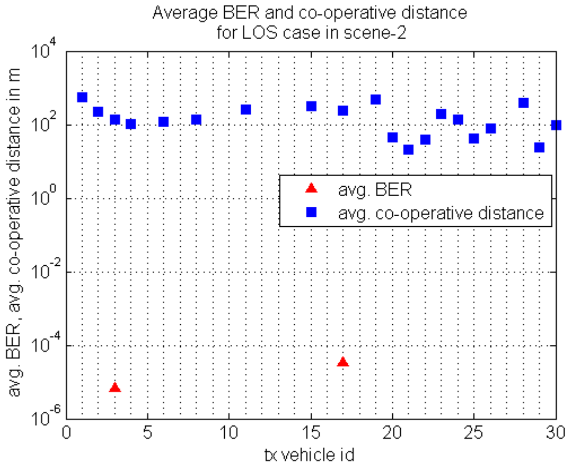

Figure 9: Average BER and co-operative distance results for LOS case in scenario-2

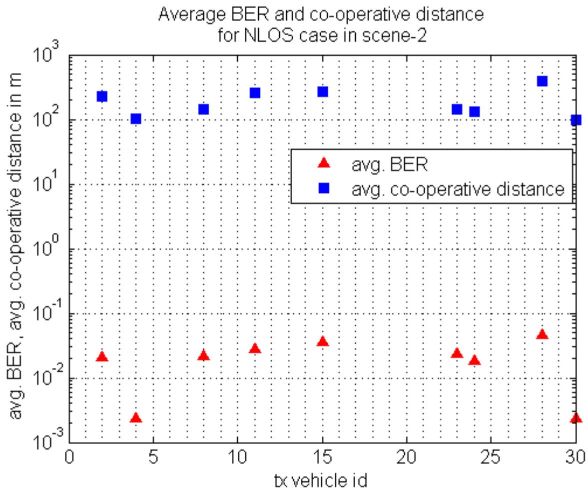

Figure 10:. Average BER and co-operative distance results for NLOS case in scenario-2

VI.CONCLUSIONS

The paper has presented on-going research being undertaken to investigate the suitability of using ZigBee technology for the intelligent systems applications. A selection of the results from experiments carried out to systematically characterise the ZigBee technology in the road domain were presented here. The ability to communicate between vehicle and roadside illustrates that well designed networks will enable efficient and discrete communications between vehicle and roadside – as the unit cost of motes will continue to go down – this is a significant contribution to the ITS domain.

In the simulation work, the co-operative distances and related average BERs for three scenarios are shown. It is found that BER values are acceptable for general data communication for vehicle safety. It is understood that Zigbee can be a suitable media for vehicle safety communication.

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