Survey on Different Railway Monitoring Applications using Wireless MAC Protocols

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***Abstract*—Advances in information and communications technology have enabled the adoption of wireless communication techniques in all sectors for the transmission of information in all forms between any two points. Wireless communications and distributed computing have promoted the development of vehicle health monitoring (VHM) systems. These have the potential for use in the monitoring of railway signalling systems and rail tracks. This paper surveys existing wireless techniques used in the railway industry for both communications and monitoring purposes. This paper proposes different railway monitoring applications and new protocol, named E-BMA, which achieves even better energy efficiency for low and medium traffic by minimizing the idle time during the contention period.**

I. INTRODUCTION

With the increased demand for railway services, overall railway infrastructure has been developing rapidly in the last two decades, including its communication systems. The lack of safety and security monitoring of railway infrastructure runs the risk of train collision, train derailment, terrorist threats, failures in the train wagon etc,

The number of accidents that take place due to the derailing of the wheels can be reduced if a system is developed which would give an indication about the increase in temperature of the wheel beyond the threshold level. The axle temperature monitoring system will give an automatic indication when the temperature of the wheel increases beyond a certain limit. The railway wagon weighing scale is a system which would effectively measure the weight of the railway wagons so that excessive loading of the wagons is avoided. These two systems are cost effective, flexible and fully automatic. These systems can replace the traditional methods which are carried out manually. The lack of safety and security monitoring of railway infrastructure runs the risk of train collision, train derailment, terrorist threats, failures in the train wagons, etc. The performance of rail vehicles running on tracks is limited by the lateral instability inherent to the design of the wagon's steering and the response of the railway wagon to individual or combined track irregularities. Railway track irregularities need to be kept within safe operating margins by undertaking appropriate maintenance programs.

An efficient railway communication system enables :

• communication between drivers and signallers at any time from any point of the station.

• all drivers in a certain area can communicate through a broadcast channel and be informed about any potential hazard.

• the train's driver can communicate with signallers and the control station in an emergency.

• signallers be informed about train location on the track.

• reduction of the number of incidents relating to signalling faults and failures.

• availability of timely and accurate information on train schedule to passengers.

• driver to know the internal conditions of wagons attached to the locomotive.

• provisioning of high security and reliability in all sectors of communications.

In this paper we summarise the applications of wireless communication standards used in the railway industry, although not all the applications are currently in use. This paper is organised as follows. Section 2) Track Monitoring system. Section 3) Motion sensors for railway monitoring. Section 4) Colibrys Accelerometers for Railway technology. Section 5) Schedule-Based medium access controle protocol. Section 6) wireless sensor networking techniques .

II. TRACK MONITORING SYSTEM

Track monitoring systems play a vital role for the safety of railroad tracks by monitoring settlement and twist. The systems are installed on tracks that may be affected by nearby tunnelling or excavation. Durham Geo Slope Indicator Company introduces a track monitoring system whose key features are: continuous, unattended monitoring with immediate processing of data, introduce three alarm systems for necessary warning, possible to observe real-time profile of the track, and real-time settlement or elevation at each sensor.

The main components of the track systems are:

• Track settlement sensor: Track settlement sensors are

mounted directly on the sleepers, parallel with the rails.

With continuous tensioned rails, sensors are anchored in the ballast rather than to the ties.

• Track twist Sensors: Track twist sensors are mounted on the long-axis of the tiles to monitor the track twist.

• Data Acquisition System: A data logger is used to read the sensors continuously. Sensed data is sent to control station over cable or telemetry link.

• Data Processing: Argus software processes the readings from data logger and displays the process data to the web. Slope Indicator introduces a full range of geotechnical and structural sensors for monitoring tilt, displacement, pressure, and strain. Recently they implemented the monitoring system in the new Metro Rail project in Perth, Western Australia.

This project is an ambitious extension to the existing light rail network that services Perth and its suburbs over 163 kilometres of rail, 20 bridges and structures, and 16 stations. More than 3000 monitoring devices will be placed along the route of the tunnel to monitor surface and subsurface movements due to excavation and tunnelling operations. Alarm levels have been established for critical instruments and if alarm levels are exceeded, incidents can be investigated and corrective actions taken as required.

III. MOTION SENSORS FOR RAILWAY TECHNOLOGY

Motion sensors find a variety of applications in the areas of railway technologies. Typical examples are:

• Bogie monitoring and diagnostics system for security and comfort

• High-speed train tilt control system for improved passenger comfort

• Position monitoring of magnetic levitation train

• Control system

• Health and Usage Monitoring System (HUMS)

• Shock monitoring during transportation

• Precise train positioning

• Railway track monitoring system for safety and maintenance.

IV. COLIBRYS ACCELEROMETERS FOR RAILWAY TECHNOLOGY

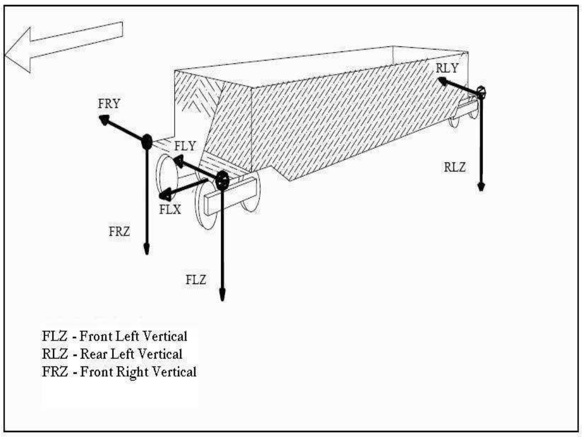

Fig. 1. Accelerometer locations and Axis naming convention.

There are many opportunities for motion sensors products to be used in the railway technology market. Colibrys MEMS capacitive accelerometers are already well recognized for their high reliability in harsh environment and have already been successfully qualified for safety critical railway applications. One of the latest and most important qualifications of MEMS capacitive accelerometers in trains has been for the tilt monitoring system in the latest generation of German ICE high-speed trains. Siemens has developed a bogie monitoring system that detects wear within bearings, shafts, brakes or wheels and identifies any potential bogie instability that could provoke an accident. This is the first bogie monitoring system designed and manufactured ever by Siemens Mobility. This highly innovative bogie monitoring system uses 24 Colibrys sensors per wagon and some 200 sensors per train.

MEMS capacitive accelerometers are the best candidates for the fast growing railway market of high speed-lines in most countries and the deployment of new generation of high-speed trains which will be more and more equipped with onboard safety control equipment requiring reliable and high specification accelerometers. Colibrys is the right partner to provide the best and adequate accelerometers for your railway applications.

V. SCHEDULE-BASED MAC PROTOCOLS

The major requirements of a wireless MAC protocol are: energy efficiency, scalability, latency, fairness, and bandwidth utilization. Contention-based protocols are scalable and adaptable to node density or traffic load variations. However, these schemes have a major limitation relating to an enormous amount of energy wasted due to collisions, overhearing, and idle listening. Schedule-based protocols are collision free and, hence, trim down the wastage of energy due to collision. However, they lack the flexibility and scalability inherent in the contention-based protocols.

a) Low-energy adaptive clustering hierarchy (LEACH):-

An architecture for wireless microsensor networks, incorporates the features of cluster-based routing and

MAC protocol. This protocol achieves energy efficiency and low latency while maintaining application-specific quality. LEACH allows all data from nodes within the cluster to be locally processed in the CH that reduces the data set. Data aggregation was done to combine several correlated data signals into a smaller set of information, and then, the resultant data were sent to the BS using a fixed spreading code.

b) Time-Division Multiple Access(TDMA):-

It is a schedule-based MAC protocol where the transmission channel is divided into several time slots, and each node is assigned a time slot. Each node wakes up and transmits data only in its allocated time slot and remains in sleep mode in the remaining time slots, However, this protocol only uses the node energy efficiently when the traffic load is high. Nodes with empty buffers keep their radio turned on during their scheduled slot and,
hence, dissipate some of their remaining energy. The energy efficient TDMA (E-TDMA) reduces energy consumption due
to idle listening. Sensor nodes keep their radios off when there is no data to transmit. However, the CH has to keep the radio on all the time and hence waste energy.

The energy consumption of EA-TDMA is significantly less than TDMA at low traffic loads, although this gap diminishes at high traffic loads. This protocol also outperforms BMA protocol in all traffic conditions except very low traffic.
The railway-wagon health monitoring system requires the MAC protocol to be capable of handling steady traffic and energy efficient. Although some of the aforementioned protocols were customized to achieve energy efficiency, this paper further explores the achievement of better energy efficiency. In addition to the EA-TDMA protocol in this paper, the authors propose a new energy-efficient WSN MAC protocol, named E-BMA.

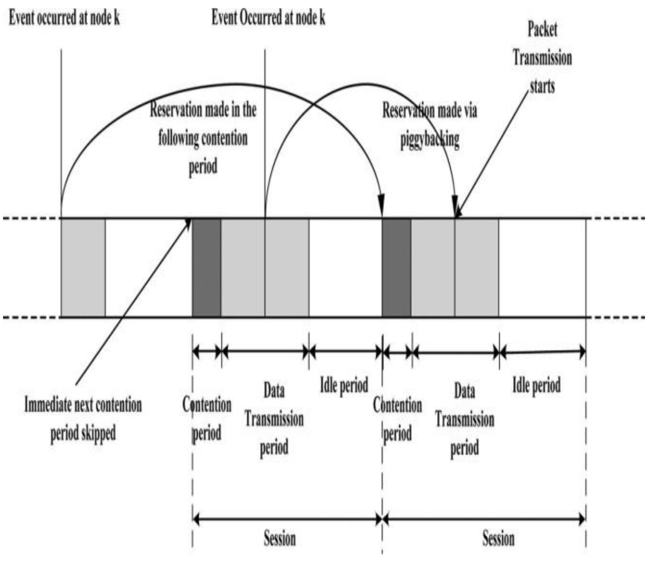

Fig 2:-Operation of the E-BMA protocol.

C) ENERGY EFFICIENT E-BMA PROTOCOL

The BMA protocol consumes less energy than TDMA at low and medium traffic loads, whereas in the energy-efficient version, EA-TDMA consumes less energy than BMA, unless the traffic load is very low. The contention phase in BMA helps to minimize the idle listening period during the data transmission phase; however, the contention phase itself consumes a certain amount of energy before each frame transmission. The energy consumption in the contention phase is paid off at light traffic loads. However, at high traffic loads, this contention phase turns into an overhead as the probability of data transmission becomes almost certain. In the proposed E-BMA protocol, the source nodes use piggybacking to make the reservation of the corresponding data slot rather than sending a control message during its allocated contention slot, as shown in Fig.2.
Operation of the E-MBA protocol is divided into rounds,
And each round is comprised of a setup phase and a steadystate phase. The steady-state phase is comprised of a contention phase and a data transmission phase. Both cluster formation and CH selection occur in the setup phase. All non-CH nodes reserve the data slots in the contention phase, whereas data transmission from source nodes to the CH occurs during the data transmission phase.

Setup Phase: Considering the specific application area and its simplicity, it is assumed that the network consists of multiple fixed clusters. In each of the clusters, there is one CH located in the center of the cluster. Based on the application and cluster size, direct transmission for data communication between source nodes and the CH is considered instead of multihop data transmission. In the setup phase, the CH informs all nodes about the start of the current round, frame start/stop time, and number of frames in a round.

Contention Phase: Each node is assigned a specific slot in the contention phase. A node transmits a 1-bit control message during its scheduled slot to reserve a data slot if it has a data packet to transmit; otherwise, the node remains in sleep mode during that contention slot. After the contention period is completed, the CH sets up and broadcasts a transmission schedule for the source nodes. However, unlike BMA, the source node does not make the reservation immediately after the data becomes available. Instead, the source node keeps the data packet in the buffer, and it waits for one frame duration to see if there is a consecutive data packet to send.

Data Transmission Phase: The data transmission phase contains one or more frames. The size and duration of each frame is fixed. Nodes send their data to the CH at most once per frame during their allocated time slot. During the data transmission phase, each source node turns on its radio in its allocated data slot and transmits data to the CH. If there are consecutive packets, the transmitted data packet conveys that information through piggybacking.

CONCLUSION

The performance of rail vehicles running on railway tracks is governed by the dynamic behaviors of railway wagons, particularly in the cases of lateral instability and track irregularities. In this paper, considering the traffic conditions of the intended application, an energy-efficient WSN MAC protocol has been investigated to monitor typical dynamic behaviour of railway wagons. A train consists of several wagons attached to a locomotive. Train health quality indicators of interest include wagon vibrations, temperature, and humidity. These vehicle health monitoring (VHM) systems for railways are used to monitor these quantities inside wagons for proactive prevention of disastrous accidents.

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