# A Wireless Subway Collision Avoidance System Based on Zigbee Networks

Qianrong Gu[1], Hongying Zuo[2], Ruidan Su[3], Kunlin Zhang[1], and Huaiyu Xu[1*]
[1]Shanghai Advanced Research Institute Chinese Academy of Sciences, China
[2]Pactera Technology International Ltd. China
[3]College of Information Science and Engineering, Northeastern University, China
Email:[1]gu.qianrong@gmail.com, [1]zhangkl@sari.ac.cn, [1]xuhuaiyu@sari.ac.cn, [2]zuo_hongying@pactera.com, [3]suruidan@ieee.org

***Abstract***—A wireless subway collision avoidance system based on zigbee network is proposed in this paper. In the proposal, all the zigbee nodes are divided into two types, fixed nodes and mobile nodes. The fixed nodes are deployed in tree topology networks overlapped with each other along the subway tunnel; the mobile nodes are installed on the trains. The core idea is as soon as a fixed node establishing an association with a mobile node, the fixed node broadcasts the event with MAC address of the mobile node immediately. By listening the broadcasted messages, other nodes can deduce position of the mobile node currently being associated. In such a way, the overlapped zigbee networks can locate positions, detect abnormal stop of trains and broadcast these information to other trains in the tunnel. With each train knowing position of the train ahead of it, the collision can be avoided. The proposed zigbee network system is evaluated by ns-2, simulation results are presented.

***Index Term***—wireless network, zigbee, train collision avoidance

## I. Introduction

Though complicated technologies and expensive equipments are extensively applied in subway control systems, collision accidents still happen occasionally. Currently a lot of railway collision avoidance systems make use of GPS data to locate train positions in railway tracks[1], [2]. But for subway scenarios, GPS signals cannot penetratesoil to reach underground tunnels. Other methods must be developed to locate train positions in the subway tunnels to avoid collisions.

Zigbee is a specification for low rate wireless communication protocol built on top of IEEE 802.15.4 standard[3]. Zigbee specification supports three kinds of network topologies, namely star, tree and mesh network; and divides zigbee devices into three types, i.e. coordinator, router and end device. A zigbee network is initialized, maintained by a coordinator. Routers and end devices join a zigbee network by means of association. Low cost and low power are two significant features of Zigbee devices. These two features make zigbee suitable for wireless sensor network applications where a wide range of area needs to be covered by a large number of network nodes, for example in a scenario of subway system.

In this paper we propose a subway collision avoidance system based on zigbee networks. The association mechanism of zigbee protocol is utilized to locate train positions in subway tunnels. Then, the obtained position information is broadcast to nearbytrains through zigbee networks. Thus, each train in the tunnelknows position of other trains in the vicinity; moreovereach train has ability to independently judge whether the trains nearby are stopped by analyzingreceived position information.If distance between two trains is less than a preset value, the train behind can apply brake in time to avoid collision.

The remainder of this paper is organized as follows: Section 2 explores the feasibility of the proposed method; section 3 describes the whole system in detail, including deployment of zigbeenetworks, network topology, cooperation between the zigbee networks and trains, and so on; Section 4 describes experimental settings under NS-2 simulation environment; experimental results are given out and discussed in Section 5; finally conclusions are drawn in Section 6.

## II. Feasibility

In subway systems, length of railway between two stations is about 1.5km at average, at maximum does not exceed 3km. In zigbee networks, the maximum dep of nodes namely *nwkMaxDepth* can be 255[3], which means the maximum diameter of a zigbee network can reach as much as 510 hops[3]. Transmission distance between two zigbee nodes (one hop) can be up to 100 meters in open space[3]; according to our experiments, reliable transmission range of one hop is about 18 meters over straight segment, and about 12 meters over curve segment of railway inside subway tunnel.Thus,if average distance between two nodes is set to 15m, azigbee network can cover 7.6km length of railway.

From statistics data, average speed of train in subway tunnel is under 50km/h, the maximum speed occurred at straight segments does not exceed 90km/h. For an average hop distance of 15m, travelling time through one hop range is 1.08s and 0.6s for the average speed and the

Manuscript received July 18, 2013; revised September 20, 2013.
Corresponding author: gu.qianrong@gmail.com
doi:10.12720/jcm.8.9.561-565

 

maximum speed, respectively.In a zigbee network, typical time need for a zigbee device to join in is 30ms[4]; the minimum interval between beacons periodically sent out by zigbee routers is 15.36ms[4]. Both are faster enough comparing to the travelling time of one hop distance.

According to the above description, spatial coverage capabilityand processing speed of zigbeenetworkare fully capable to be applied in a system aiming to avoid collision between subway trains.

## III. System Design

In order to locate position of trains in subway tunnel, zigbee networks are deployed in tree topology overlapped with each other along the tunnel [5]. As shown in Fig. 1, each individual zigbee network covers two sections of railway between three stations;each section of railway between two stations is covered by two different zigbee networks using different channels to communication.Coordinator of each network is deployed at station platform. Each platform has only one zigbee coordinator.

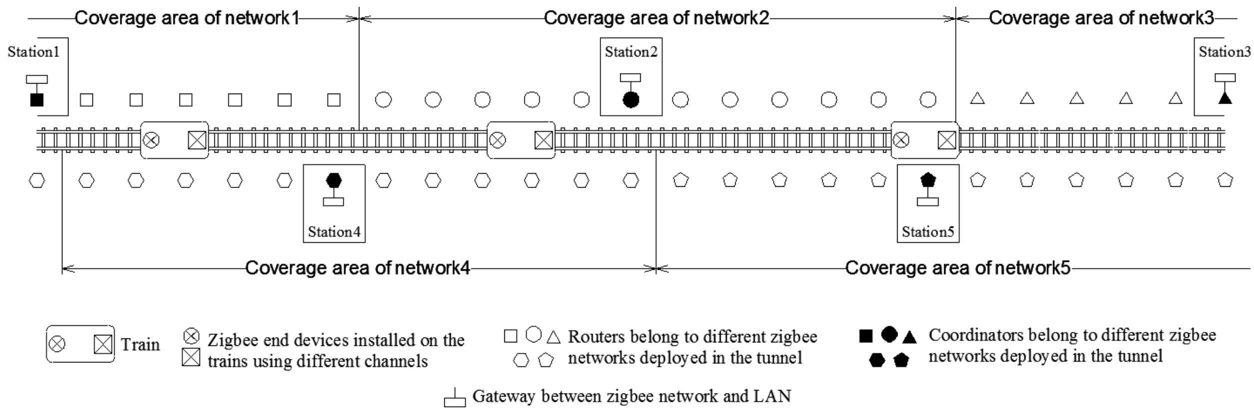


Figure. 1. Deployment of zigbee networks in wireless subway collision avoidance system

All the nodes deployed in the tunnel are zigbee routers. Zigbee coordinators and routers are fixed in positions and used as position flags. The distance between two routers is 16m and 10m in straight segments and curve segments of railway, respectively. The position data of all the fixed nodes are saved into a position table. Byknowing router address and EPAN ID of network the router belongs to, the position of this router in the tunnel can be determined immediately by looking up the position table.All the nodes installed on the trains are zigbee end devices and defined as mobile nodes, their MAC addressescan beused to identify different trains.

Some NIB attributesofzigbee networks are set to values as listed in Table I. The default distributed addressing schemedescribed in zigbeespecification[2] is used to assign addresses to all the nodes.The *BeaconOrder* parameter in network descriptor is set to 0x00 to specify nodes in fixed positionsto transmit beacons at 15.36ms interval.

Table I. Value of Some NIB Attributes

| Attributes | Value | Description |
|---|---|---|
| nwkMaxDepth | 0xff | The max depth of network is 255. |
| nwkMaxChildren | 0x02 | The number of children a node can have is 2. |
| nwkMaxRouters | 0x01 | The number of router a node can have as child is 1. |
| nwkAddrAlloc | 0x00 | Using distributed addressing scheme |

The mechanism to determine train positions by a zigbee network is diagramed in Fig. 2. When a mobile node enters the range of a new zigbee network with train, this must happen at platform because the boundary of two networks is located at platform (see Fig. 1), it joins the new zigbee network by meanings of association with router No.1 as shown in Fig. 2. As soon as router No.1 accepted the mobile node, it broadcasts this event with MAC address of mobile node to other nodes in the same network. Since router No.1 is a fixed node, its position data is saved in the position table beforehand, thus the position of a specific mobile node (train) can be figure out by other nodes though looking up the position table when they receive the broadcasted message.

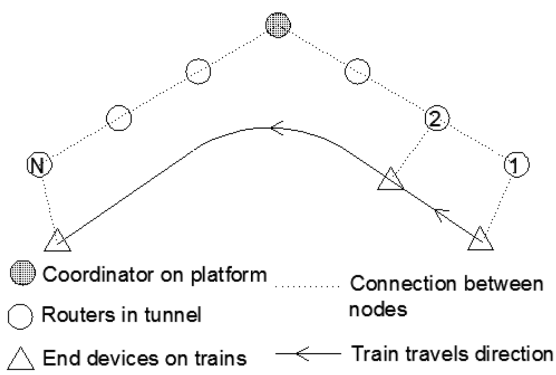


Figure. 2. Train position determining mechanism

During the process of moving from router No.1 to router No.2, the mobile node keeps on monitoring beacons periodically transmitted by fixed nodes nearbythrough a channel specified to this network. If the mobile node findslink quality of router No.2 is better than that of router No.1, which implies it is closer to the router No.2, then the mobile node leaves router No.1 and rejoins the network by associating with router No.2. After router No.2 accepted the mobile node, it broadcasts out this event immediately; and it will continue broadcasting messages like "the mobile node is beside me" periodically untilthe mobile node leaves it.This process is repeated while the train moving further from router No.2 to router No.n as diagramed in Fig.2.

The processing steps of fixed nodes are:

1. Transmit beaconthrough specified channel.
2. If there is a join request from a mobile node,
   a) Accept the mobile node.
   b) Set hasAssociatedNode to True.
3. If there is a leave request from a mobile node,
   a) Set hasAssociatedNode to False.
4. If receive a broadcast message,
   a) Relay the message.
   b) If hasAssociatedNode is Trueand if MAC address in the message is same as the address of the associated node,
      1) Set hasAssociatedNode to False.
5. If hasAssociatedNode is True,
   a) Broadcast the MAC address of the associated mobile node.

The processing steps of mobile nodes are:

1. If receive a beacon on specified channels,
   a) If hasAssociated is True,
      1) If it is from the associated fixed node,
         IV. Update the associated link quality(LQ).
      2) If it is from other fixed nodes,
         i. If LQ is better than that of associated Node[6],
            ✓ Set hasAssociated to False.
            ✓ Leave the currently associated node.
            ✓ Join the node with better LQ.
            ✓ Set hasAssociated to True.
            ✓ Determine current position by looking upaddress of the newly associated node in the position table.
   b) If hasAssociated is false,
      1) Join the node.
      2) Set hasAssociated to True.
      3) Determine current position by looking up address of the associated node in the position table.
2. If receive a broadcast message,
   a) Determine position of the node issued broadcast.
   b) If distance to the node issued broadcast is less than a preset value,
      1) brake.

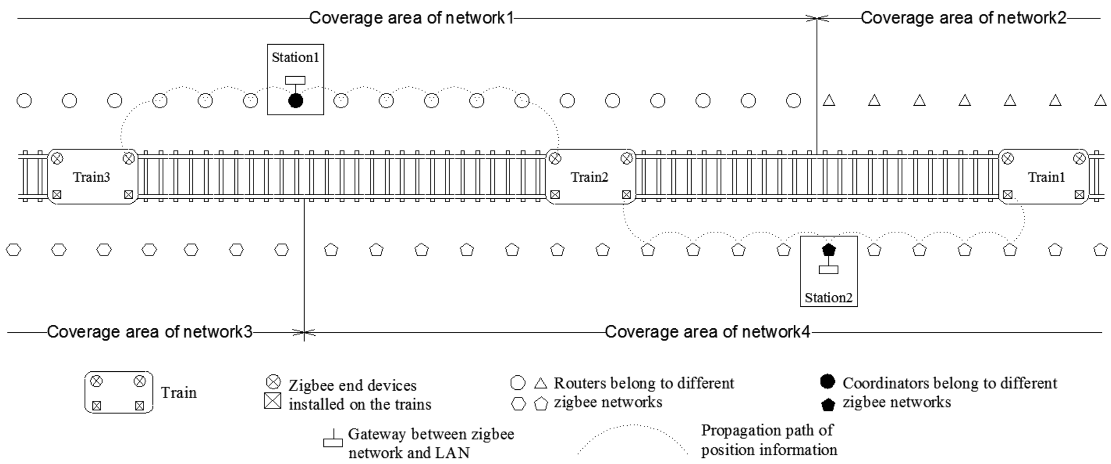


Figure. 3. Cooperation between the zigbee networks and trains

Cooperation between the zigbee networks and trains is illustrated in Fig. 3. Each trainis equipped with 4 zigbee end devicesdivided into front and rear group as shown in Fig. 3. In order to avoid two mobile nodes in a group joining the same zigbee network, each node in one group is specified a different radio channel corresponding to the channels of two overlapped networks covering the location where the train is in.

As Fig. 3 shows, when Train1 move toward to Station2, position information of the head of Train1 propagatesforward though network4 and finally reach Train2; position information of the rear part of Train2 propagates backward though network4 to reach Train1. Similarly, Train2 and Train3 communicate position information with each other through network1 which covers their location.The coordinator of each zigbee network connects to a gateway of LAN. The position information of trains in each zigbeenetwork is transmitted to control center of the subway through these gateways.Each train can know the positions of other trains in the network same as the one it is in, and in the networkoverlapped with the network it is in; the control center can know the positions of all the trains in the subway systems through the data transmitted by gateways; therefore, collision can be avoided.

## V. EXPERIMENTAL SETTINGS

NS-2[7]was used to simulate the system proposed in section 3. The railway is a closed curve with a length of 60km, consisting of several straight and curve segments. A total of 30 stations are added to the subway system. The minimum, average and maximum distance between two stations is 1.5km, 2km and 3km, respectively. The total number of zigbee networks deployedin simulation is 30. The minimum, average and maximum distance between two fixed nodes, namely routers or coordinator, is 10m, 15m and 16m, respectively.The average length of railway covered by a zigbee network is 2km; the average number of fixed nodes in a network is 267.The Total number of fixed nodes is 8010.

The train length is set to 120m. Each train has four zigbee end devices, namely mobile nodes, with two in the front and two in the rear. The average acceleration and deceleration rate of trainis $1.0m/s^2$ and $1.2m/s^2$[8], respectively. The maximum speed of train issimulated from 50km/h to 90km/h at an interval of 10km/h. The length of safe zone between two trains is 350m.

The movement strategy of trains in simulation is:

1. Stop 30 seconds at each station.
2. Departure with the maximumacceleration rate until:
   a) Reach the maximum speed.
   b) Encounter the safe zone oftrain in frontof it.
   c) Receive a randomly issued stopcommand.
3. When reach the maximum speed, keep the speed until:
   a) The train needs to brake to stop at the next station.
   b) Encounter the safe zone oftrain in front of it.
   c) Receive a randomlyissued stop command.
4. When need to brake, brake with the maximum deceleration rate.
5. When encounter the safe zone of train in front of it.
   a) Brake with the maximum deceleration rate until stop.
   b) Wait till the train in front of it moves forward again, after a random delay time, departure.
6. Stop commands are randomly issued to trains atrandom positions other than the stations. The length of stop time is randomly selected from a range of 15s to 120s.

The system was simulated with the number of mobile nodes changing from 20 to 200, in other words, with the number of trains running on the railway changing from 5 to 50.

Simulation parameters are list in Table II.

TABLE II: SIMULATION PARAMETERS

| Parameter | Value |
|---|---|
| Network size | 30km×0.8km |
| Num of fixed nodes | 8010 |
| Num of mobile nodes | 20,40,60,80,100,120,140,160,180,200 |
| Mobility model | Freeway |
| Transmission range | 18m |
| Simulation duration | 1800s |

## VI. EXPERIMENTAL RESULTS

Fig. 4 shows the simulation results of average lost ratio of broadcast messages with 200 mobile nodes, namely 50 trains. When a fixed node is trying to relay the broadcast message to a mobile node associated with it, but the mobile node moves out of its range at the same time,thebroadcast message cannot be transmitted to the mobile node successfully.

Fig. 5 shows the simulation results of average per-hop delay time of broadcast messages. Both increments in the maximum speed and in the number of mobile nodes will cause the average per-hop delay time of broadcast messages to increase, but the inference is very limited.

Fig. 6 shows the average stop distance between two trains after the behind one encounters the safe zone of the train in front of it and brake to stop. The length of the safe zone is 350m. The increment in number of mobile nodes only has a little inference on stop distance, less than 3 meters in case of 90km/h maximum speed with mobile nodes increasing from 20 to 200.

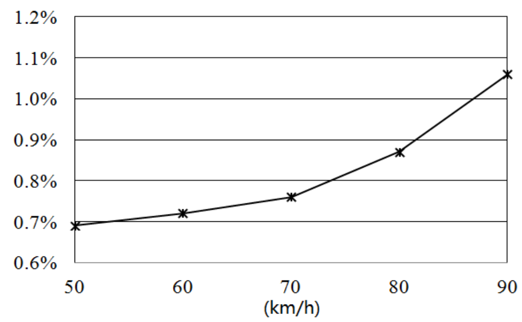


Figure. 4. Average lost ratio of broadcast messages

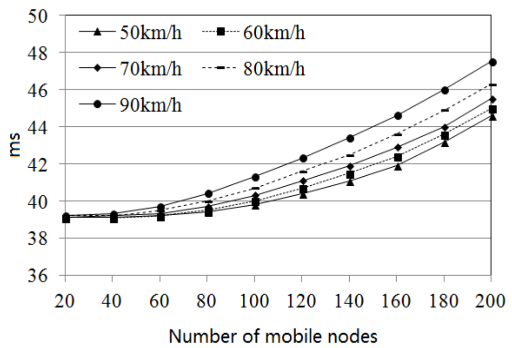


Figure. 5. Average per-hop delay time of broadcast messages

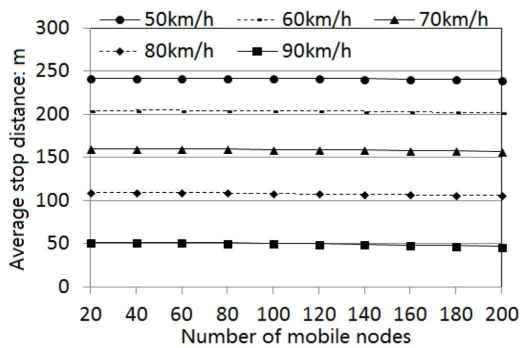


Figure. 6. Average stop distance

Table III compares theoretically calculated stop distances to the average simulated stop distance of 200 mobile nodes. The differences in stop distance shown in Table III mainly come from two factors: positioning accuracy and network transmission latency.The average positioning accuracy in this system is the average length of one hop, namely 15m. The maximum difference of 30.7m in Table III means a range of 2 hops.

TABLE III: COMPARISON OF THEORETICAL STOP DISTANCES AND SIMULATED RESULTS (WITH 200 MOBILE NODES)

| Speed(km/h) | Theoretical(m) | Simulated(m) |
|---|---|---|
| 50 | 269.6 | 252.2 |
| 60 | 234.3 | 213.8 |
| 70 | 192.5 | 168.8 |
| 80 | 144.2 | 117.2 |
| 90 | 89.6 | 58.9 |

## VII. CONCLUSIONS

Azigbee networks based Subway Collision Avoidance System is proposed in this paper. The performance of the system is evaluated by NS-2 simulation platform. According to the simulation results zigbee networks can locate the position of trains and transmit the position information among the trainsreliably and timely. The inference of position accuracy and network latency in the stop distance of trains at speed of 90km/h is about 30m, i.e. a range of 2 hops.

## REFERENCES


[1] C. R. Garcia, A. Lehner, T. Strang, and M. Rockl, "Comparison of collision avoidance systems and applicability to rail transport," in *Proc. 7th International Conference on ITS*, 2007.

[2] K. T. Mueller, "Low-Cost, precise railroad GPS vehicle location system," Final Report for High-Speed Rail IDEA Transportation Research Board, National Research Council, 2006.

[3] Zigbee Specification, 2007.

[4] ZigBee Alliance. [Online]. Available: http://www.zigbee.org

[5] M. S. Pan and Y. C. Tseng, "ZigBee-Based Long-Thin wireless sensor networks: Address assignment and routing schemes," *Int. J. Ad Hoc and Ubiquitous Computing*, vol. 12, no. 3, pp. 147-156, 2013.

[6] N. Patwari, J. N. Ash, S. Kyperountas, A. O. Hero, R. L. Moses, and N. S. Correal, "Locating the nodes: Cooperative localization in wireless sensor networks," *IEEE Signal Processing Magazine*, vol. 22, no. 4, pp. 54-69, 2005.

[7] The Network Simulator - ns-2. [Online]. Available: http://www.isi.edu/nsnam/ns/

[8] General Technical Specification for Metrovehicles, GB/T 7928-2003.



**Qianrong Gu** received his B.E. in automatic control from Shanghai Jiaotong University, China, in 1993; his M.E and PhD in electronics engineering from The University of Tokyo, Japan, in 2000 and 2003, respectively. Currently, he is a senior visiting researcher in Shanghai Advanced Research Institute, Chinese Academy of Sciences. His current research interesting is wireless sensor network.

**Hongying** Zuoreceived her B.E. in computer application from Inner Mongolia University of Technology, China, in 1998; her M.E and PhD in computer science and technology from Kitami Institute of Technology, Japan, in 2004 and 2006, respectively. Now she is a senior software project manager in Pactera Technology International Ltd.China.

**Ruidan Su** received his BE from South China Normal University in 2006 and his Master's Degree in Northeastern University in 2010.He is currently pursuing his PhD with computer science and computer application of technology in Northeastern University. He had published more than 10 papers during his MD and Ph.D study in Northeastern University.

**Kunlin Zhang** received his B.E. and M.E. in software engineering fromNortheastern University, China, in 2010 and 2012, respectively. Currently he is a software engineer in Shanghai Advanced Research Institute, Chinese Academy of Sciences.

**Huaiyu Xu** received his B.E and M.E. in computer application from Northeastern University, China, in 1991 and 1994, respectively; his PhD in electronics engineering from The University of Tokyo, Japan, in 2002. Now he is a senior research fellow in Shanghai Advanced Research Institute, Chinese Academy of Sciences.