2010 Fourth International Conference on Genetic and Evolutionary Computing

Performance analysis of three-tiers Wireless Sensor Networks for Urban Traffic Information Monitoring

Huaping Yu
College of Computer Science, Yangtze University, Jingzhou, China
yhpjz@126.com

***Abstract*—This paper presents an urban traffic information collection algorithm implemented through Wireless Sensor Networks (WSNs) with floating vehicles technology, which can provide a flexible, energy efficient, low-delay and low-cost wireless solution for obtaining all-weather real time traffic information that can be used for generating safety warnings to drivers, passengers and managers. The system consists of an urban traffic control center (TCC), some intersection control units (ICUs), some floating vehicles nodes (FVNs) and vast roadside sensor nodes (RSNs), which make up a three-tiers network architecture. Moreover, the system performance has been detailedly analyzed and evaluated in terms of delay and energy. And the result shows that the proposed algorithm can not only ensure the urgency data to be propagated but also effectively prolong the network lifetime. It is characterized with higher cost performance and flexibility, comparing with the current system based on single floating vehicles technologies or single WSNs technologies.**

Keywords- intelligent transportation systems; wireless sensor networks; urban traffic information collection; delay; energy

I. INTRODUCTION

Urban traffic planning and management is confronting substantive pressure with the rapid growth of roads, vehicles and population, which results in traffic congestion, economic loss, traffic accident and environment pollution that badly affect the city development. Intelligent Transportation Systems (ITSs) have been developed and been evolving to support the driving safety and transportation efficiency through the information computing and communications among transportation infrastructures and vehicles without costly expansion [1].

Wireless sensor networks (WSNs) consist of a large number of resource-limited, self-organized, low-cost sensor nodes linked by wireless communication module equipped on the nodes to perform distributed sensing and acting tasks. [2]. In WSNs, each sensor node is also equipped with various kinds of sensors, computation units, and storage devices which enable sensor nodes to be easily and rapidly deployed to cooperatively gather, process, and transmit information. WSNs are now used in many civilian and military application areas, including industrial process monitoring and control, environment and habitat monitoring, healthcare applications, traffic control, home automation, scientific exploration and battle surveillance.

In this paper, we propose an urban real time traffic information collection algorithm based on hierarchical WSNs with floating vehicles. These sensors are deployed along roadsides or on floating vehicles to detect traffic flow, traffic accident, speed of vehicle, and lane occupancy rate continuously.

The rest of this paper is organized as follows. Section II looks into the related works. In Section III, we describe the network architecture and data operation fashion. Section IV describes the delay and energy performance, and shows the simulation results. Finally, we conclude the paper in Section V.

II. RELATED WORK

Traditionally, traffic information is gathered by monitoring the roads through video cameras and inductive loops, which are connected by copper wires or fiber-optic cables [3]. But, the practice has proved that these approaches are unlikely to popularize because some problems with them. For example, the required dedicated equipments are prohibitively expensive. And they involves much human labor. Furthermore, video cameras can not work well when the weather is bad due to the limited visibility. Lastly, deploying inductive loop is very difficult.

Floating vehicle technology has been widely used to road safety and many commercial applications [4] , [5]. The solution utilizes the communication of inter-floating vehicles to gather traffic information on the urban major road network. Of course, the solution also has disadvantages such as long delay, service condition-limited (e.g., floating vehicles can not collect data from some road segments which they are not able to arrive due to the abominable weather, traffic congestion, etc.).

Recently, researchers have proposed WSNs applied in the area of ITS [6], [7], [8]. It is obvious that WSNs have many advantages to construct ITS in terms of the cost performance, flexible and control efficiency. For example, WSNs can monitor the road traffic information and estimate road state unremittingly without manual intervention and work at the night and abominable weather. WSNs can provide low delay and high precision network performance.

978-0-7695-4281-2/10 $26.00 © 2010 IEEE
DOI 10.1109/ICGEC.2010.204

The fundamental problem of this approach is the non-uniformity of energy consumption among the sensor node, which subsequently generates the energy "hot spots" and reduces the lifetime of WSNs.

III. SYSTEM DESCRIPTION AND ANALYSIS

In this section, we propose a new urban real time traffic information collection algorithm based on hierarchical WSNs with floating vehicles to solve the disadvantages of data collection algorithms are analyzed in section II.

A. Network Architecture

1) The system architecture of urban ITS

The urban ITS is a synthesis traffic management and services system. The system architecture is as illustrated in Figure 1. In the figure, the urban real time traffic information collection system is the foundation of the whole ITS.

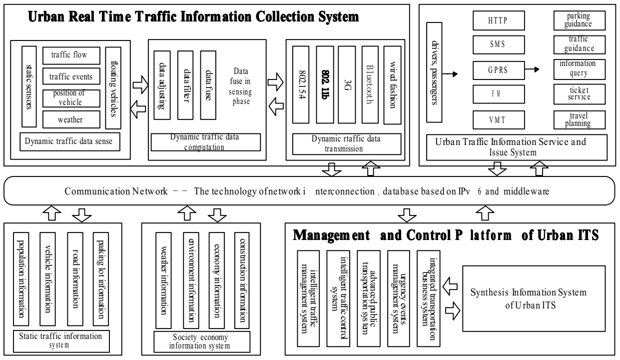

Figure 1. The system architecture of ITS

2) The three-tiers network architecture of WSNs with floating vehicles

The network comprises four elements, roadside sensor nodes (RSNs), floating vehicle nodes (FVNs), intersection control units (ICUs) and urban traffic control center (TCC). Figure 2 shows the three-tiered network architecture of data collection algorithm that we proposed.

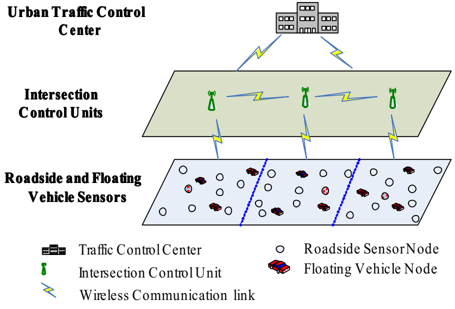

Figure 2. The three-tiered network architecture of WSNs with floating vehicles

The bottom tier consists of a large number of RSNs and FVNs. RSNs are densely deployed on two sides of roads and each node is aware of its own position. They are used to sense the real time road traffic information such as vehicle speed, traffic flow, lane occupancy rate, queue length, traffic congestion state, traffic accident and weather information, etc. RSNs are constrained in energy, processing and storing abilities, especially the energy can not be recharged, so that they periodically open the radio to transmit sensed data, but in other time they will sleep to save energy. FVNs are usually installed at floating vehicles (such as buses, taxies etc.) so that they are active and not constrained to the energy. They continuously collect the data from RSNs and transmit the data to ICU. The middle tier consists of many ICUs deployed on crossroad which can control the traffic lights and traffic guidance information board. And the top tier is the urban TCC which can form overall analysis and decision-making. ICUs and TCC have abundant computing and storage resource compared to RSNs and FVNs, their energy can be recharged in time.

It is obvious that this architecture based on WSNs has notable predominance compared to video cameras and inductive loops connected by wired fashion in terms of maintenance convenience, application flexibility and cost of system etc.

B. The Data Operation Fashion

Generally, urban real time traffic information may be classified into urgency data (e.g. traffic accident, traffic congestion, abominable weather etc.) and non-urgency data (e.g. normal traffic flow). we use different data collection approaches to deal with them by setting TTL field, T_{wait} field and Type field in data packet, which can improve the algorithm performance in terms of delay, energy, self-adaptation and robustness etc. The data packet format of traffic information is as illustrated in Figure 3. In the figure, Type denotes the type of data packet (that is urgency data and non-urgency data); TTL (Time To Live) denotes the lifetime of data packet ; T_{wait} denotes the longest waiting time of data packet in source RSN memory.

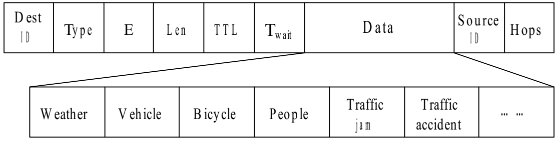

Figure 3. Data packet format of urban traffic information

The procedure of data collection is as shown in Figure 4. Firstly, The data packet generated by RSN is cached in its memory. And then if the data packet is urgency data, the data packet will be transmitted through multi-hops mode on RSNs to ICU directly. or else, The data packet will wait a set time (that is T_{wait}) in RSN memory until a FVN arrives. If no FVN arrives within the set time, the data packet will use multi-hops mode on RSNs to ICU also. Furthermore, if the TTL of data packet expires in the process of transmit the data packet to ICU via FVNs, the data packet will be relay to a near RSN immediately and then use multi-hops mode on RSNs to ICU. Lastly, ICU relays the data packet to urban TCC directly via wireless or wired fashion. It is obvious that we have the reasonable in equation $TTL >> T_{wait}$.

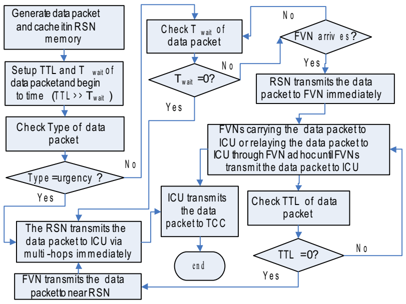

Figure 4. The data delivery flow chart

IV. PERFORMANCE ANALYSIS AND EVALUATION

In this section, we first analyze the delay and energy performance of our proposed algorithm, and then give the simulation results.

A. Delay Analysis

The data delay is referred to the duration from data generation to data reception by urban TCC. We have the equation (1) from above analysis.

$$D_{total} = \tau_{ri} + \tau_{it} \qquad (1)$$

In (1), τ_{ri} is referred to the duration from data generation to data reception by an ICU, τ_{it} is referred to the duration from ICU to data reception by TCC. It obvious that τ_{it} is steady and $\tau_{it} << \tau_{ri}$, so we only analyze the τ_{ri}.

1) The delay model of τ_{ri}

From the analysis in section III.B. If the data packet is relayed to ICU via multi-hops on RSNs, the τ_{ri} will very little and E[τ_{ri}^{rsn}] is computed as follows [9]:

$$E[\tau_{ri}^{rsn}] = \sum_{i=1}^{n} \tau_i = n \times k \times r \qquad (2)$$

In (2), τ_i is referred to the duration from a RSN to next RSN, n is the number of multi-hops to ICU, k denotes the length of data packet and the r denotes the communication radius of RSN. If the data packet is transmitted to ICU via FVNs. The delay model [5] is as shown in Figure 5.

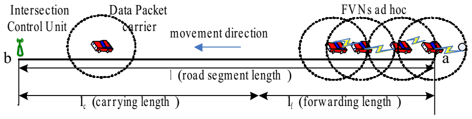

Figure 5. Data packet delay model based on floating vehicle nodes

In the figure 5, The procedure of relaying data packet on FVNs is classified into forwarding phase and carrying phase. In forwarding phase, some FVNs form an ad hoc network to transmit data packet to ICU. When these FVNs can not form an ad hoc network, the FVN that lastly receives the data packet carries it to ICU. We compute the data packet travels time (that is E[τ_{ri}^{fvn}]) as follows [5]:

$$\begin{aligned} E[\tau_{ri}^{fvn}] &= E[\tau_{ab}] = (l - E[l_f]) / v \\ &= (l - E[vT_h \mid T_h \le R] \times P[vT_h \le R] / P[vT_h > R]) / v \end{aligned} \qquad (3)$$

In (3), R denotes communication radius of FVN; v denotes average speed of FVN when it carries data packet; T_h denotes the inter-arrival interval of the h-th vehicle and the (h+1)-th vehicle. T_h is assumed to be an exponential random variable and this assumption has been shown valid in [5].

2) Impact of the number of floating vehicle arrival per hour and speed of floating vehicle on delay

The impact of the number of floating vehicle arrival per hour (marked as λ) and speed of floating vehicle (marked as v) on data delay (that is E[τ_{ri}]) is illustrated in Figure 6. In the figure, with the increasing of λ, the E[τ_{ri}] decreases. And the E[τ_{ri}] will not exceed the value of TTL of the data packet, which effectively ensure the urgency data packet (e.g. traffic accident, traffic jam, etc.) to be uploaded to urban TCC in time. But, when the number of floating vehicles running on the same road segment is too big, the average data packet delay will increase by contraries.

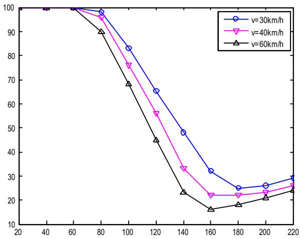

Figure 6. Impact of the number of floating vehicle arrival per hour and speed of floating vehicle on delay

B. Energy Analysis

In our approach, ICUs and TCC have abundant energy because they can be recharged conveniently, but RSNs are constrained in energy and their energy can not be recharged. So we use the floating vehicles to transmit non-urgency data packets to ICU and that use multi-hops on RSNs to transmit urgency data packets to ICU, the main target of which is to move the burden of more communication tasks to FVNs.

1) The strategy of prolonging network lifetime

a) Deployment strategy of roadside sensor nodes

In order to avoid unbalanced energy consumption in RSNs, we use the deployment strategy of RSNs (as shown in Figure 7) to prolong the lifetime of network [10].

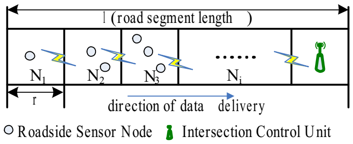

Figure 7. Deployment strategy of roadside sensor nodes

In the figure 7, r denotes communication radius of RSN, and The road segment is divided into n (n=[l/r]) sections. and Let N_i be the number of RSNs in the i-th section ($i \in [1, n]$), E_i denotes the total energy consumption of RSNs in the i-th section includes sensing, computing, transmitting and relaying data packets. We have:

(4)

Moreover, We can further prolong the network lifetime by scheduling RSNs to active state and sleeping state. that is, Each section has only one active RSN to sense and relay data packet to ICU in the same time.

b) Data fuse technology

The data fuse technology is referred to the methods for combining data into a small set of meaningful information, which can improve the energy performance of network in an order of magnitude by reducing the amount of data transmitted in the network. The data fuse technology can be lossless or lossy. In lossless aggregation, more information is embedded into a single packet thereby combining all headers into single header and same data bits. In lossy aggregation many data packets are passed through aggregation function (e.g. sum, average, min, max, count) that generates a single packet which has no information about the original data. In our approach, the hierarchical structure of data fuse is as shown in Figure 8.

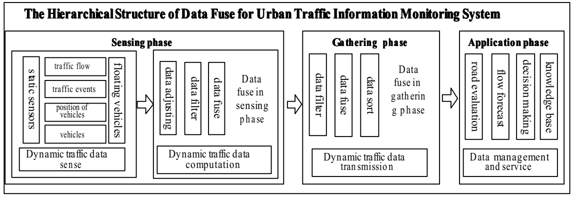

Figure 8. The hierarchical structure of data fuse for urban traffic information monitoring system

c) Floating vehicles scheduling

The floating vehicles scheduling is referred to arranging reasonable path, time interval of driving, speed of floating vehicles, which can improve the energy performance based on reasonable parameters (e.g. floating vehicle arrival rate λ, floating vehicle path, floating vehicle speed etc.).

2) Impact of the number of floating vehicle arrival per hour and speed of floating vehicle on energy consumption

The impact of the number of vehicle arrival per hour and speed of floating vehicle on energy consumption is illustrated in Figure 9.

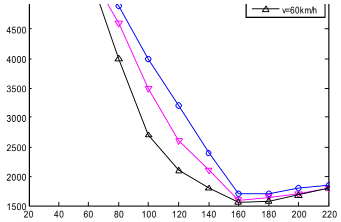

Figure 9. Impact of the number of floating vehicle arrival per hour and speed of floating vehicle on energy consumption

V. CONCLUSION

WSN and floating vehicle technologies were used in urban ITS at the same time, which realized urban real time traffic information collection algorithm. The approach is able to enhance the capabilities of gathering, managing, analyzing and issuing of urban traffic information, and improve cooperative control capability of different road segment to satisfy synthesis information requirement of users.

In the future, we plan to make further investigation of the data fuse technology for urban real time traffic information collection. And study the network cooperating work model to further improve performance of urban ITS.

ACKNOWLEDGMENT

The research is supported by Educational Commission of Hubei Province of China (Grant No. Q20101315).

REFERENCES

[1] Richard J. Weiland, and Lara Baughman Purser, “Intelligent Transportation Systems,” Transportation in the New Millennium, 2000.

[2] J.Yick, B.Mukherjee, and D.Ghosal, “Wireless Sensor Network Survey,” The International Journal of Computer and Telecommunications Networking, vol. 52, no.12, 2008, pp.2292-2330.

[3] Zhang Yuhe, Huang Xi, and Cui Li, “WSN Nodes for Real-Time Traffic Information Detection,” Journal of Computer Research and Development, vol.45, no.1, 2008, pp.110-118.

[4] J. Zhao, and G. Cao, “VADD: Vehicle-Assisted Data Delivery in Vehicular Ad Hoc Networks,” IEEE Transactions on Vehicular Technology, vol. 57, no. 3, May, 2008, pp. 1910–1922.

[5] Jaehoon Jeong, Shuo Guo, Yu Gu, Tian He, and David Du, “TBD: Trajectory-Based Data Forwarding for Light-Traffic Vehicular Networks,” Proceedings of the 29th international Conference on Distributed Computing Systems, Jun. 2009.

[6] M. Meribout, and A. Al Naamany, “A Collision Free data Link Layer Protocol for Wireless Sensor Networks and its Application in Intelligent Transportation Systems,” Proceedings of Wireless Telecommunications Symposium, Apr. 2009, pp.1-6.

[7] W. Chen, L. Chen, Z. Chen, and S. Tu, “Wits: A wireless sensor network for intelligent transportation system,” Proceedings of the First International Multi-Symposiums on Computer and Computational Sciences – vol.2, 2006, pp. 635–641.

[8] Q. Q. Malik Tubaishat, Peng Zhuang and Y. Shang, “Wireless sensor networks in intelligent transportation systems,” Wireless Communications and Mobile Computing, 2008.

[9] Yu Huaping, Guo Mei, and Hu Jie, “Delay performance analysis for Mobile sinks Wireless Sensor Networks,” Journal of Application Research of Computers, vol.27, no.1, Jan.2010, pp.317-319.

[10] Xie Wei-hao,Chen Hui-min, and Zheng Lin-shui, et al. “Wireless Sensor Network Topology for Road Traffic,” Journal of Shanghai University (Natural Science),vol.13, no.1, Feb.2007,pp.1-3.