A Self-adapting Data Collection Approach in Wireless Sensor Networks for Urban Traffic Information Monitoring

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***Abstract*—Wireless sensor networks (WSN) offer the potential to significantly improve the efficiency of existing intelligent transportation systems(ITS). Currently, collecting urban traffic information for traffic planning and management based on single floating vehicle technology has the disadvantages of long data packet delivery delay and big delay dithering. The usage of WSN in ITS is expected to be able to overcome the above difficulties. This paper proposes hybrid traffic information collection and communication algorithm based on WSN and floating vehicle technologies. And a simulation to analyze and evaluate the algorithm's performances is implemented. The result shows that the proposed algorithm can ensure the urgency data to be propagated effectively. It is characterized with higher cost performance, flexibility and control efficiency, comparing with the current ITS system based on single floating vehicle technologies or single WSN technologies.**

Keywords-wireless sensor networks; floating vehicle; data collection; intelligent transportation systems; urban traffic information

I. INTRODUCTION

Wireless sensor networks (WSN) consists of a large number of resource-limited and low-cost sensor nodes which can be self-organized to establish a network via the wireless communication module equipped on the nodes [1]. 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 collect, process, and transmit information. WSN have already found many civil and military applications, such as Intelligent Transportation Systems (ITS), health-care, environmental monitoring, scientific exploration and battle surveillance, etc.

Urban traffic planning and management are confronting substantive traffic congestion with the rapid growth of vehicles and population, especially in the city of relatively poor traffic infrastructure. ITS has been used to ensure the efficiency of urban transportation without costly expansion [2], which includes traffic information collection, traffic information analysis and decision-making, traffic information services, etc. and collecting urban real time traffic information (such as speed of vehicle, lane occupancy rate, traffic flow, traffic accident) effectively is the foundation of ITS.

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Currently, this traffic information is obtained by monitoring the roads through video cameras and inductive loops, etc., which are connected by copper wires or fiber-optic cables. Several problems arise from the existing sensor network methodology [3]. First, the required dedicated communication infrastructures are prohibitively expensive, particularly as a system grows in coverage and number of sensors increases. Second, this method involves much human labor. Furthermore, video cameras can not work well when the weather is bad due to the limited visibility. And deploying inductive loop is very difficult, too. It is obvious that WSN has many advantages to construct ITS [4]. A typical ITS based on WSN is as shown in Figure 1.

In this paper, we propose a self-adapting urban real time traffic information collection approach with hybrid WSN. These sensors are deployed along roadsides or vehicles to detect traffic flow, speed of vehicle, and lane occupancy rate continuously.

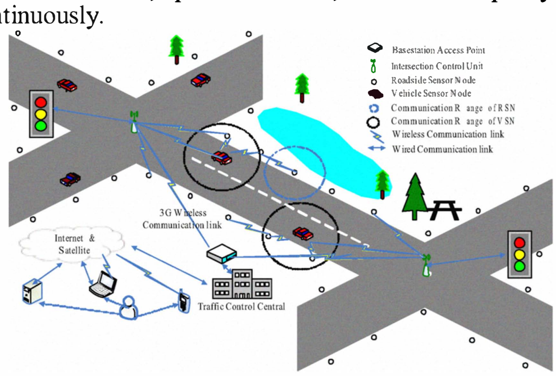

Figure 1. An Intelligent Transportation Systems based on WSN

The rest of this paper is organized as follows. In Section II, we present and discuss the related work in detail. In Section III, we describe the network architecture and proposed Hybrid WSN Data Collection(HWDC) Algorithm based on floating vehicle technologies. In Section IV, we show the simulation results. Finally, we conclude the paper in Section V.

II. RELATED WORK

ITS and WSN have been extensively explored in their respective domains, however, the combination of them has not been paid enough attention until recent years. Currently, The data collection algorithms based on WSN proposed for

ITS are classified into two categories baesd on network architecture: flat data collection algorithms and hierarchical data collection algorithms.

A. Flat Data Collection Algorithms

In these algorithms, every sensor node in the network is deployed on vehicle or roadside, which is assigned the same role in communication aspect. And these moving or static sensor nodes form single-tiered WSN architecture that is suitable for object or target tracking application. On the other hand, the main drawback of this architecture is that the sensor node has major constrains in terms of energy, computing, communication capability of the nodes. Thus, the ability of the network to support Quality of Service (QoS) is limited. The representative algorithms in flat structure include WNSW [5], WITS [6], Clustered WSN [7] etc.

B. Hierarchical Data Collection Algorithms

In this category, two or more tiers constitute the WSN architecture for ITS, which includes sensor nodes deployed on roadsides, sensor nodes equipped on vehilces, relay access points deployed on intersections. The multi-tiered architecture algorithms use hierarchical designs in order to improve the performance of the WSN in terms of delay and energy. These algorithms couple a WSN with other technologies (like WiMAX) such that higher performance can be achieved. Their main target is to move the burden of handling complex processing and computations to another layer where other technologies can be more efficient than WSN. The typical algorithms have SNMS [8], TTW-RTC [9], TBD [10] etc. But, the hierarchical data collection algorithms have three disadvantages as follows:

- Dealing with different technologies to communicate between different tiers adds to the complexity of the system design.
- Data packet delay is longer than the delay of single-tiered WSN architecture. and The urgency data packet can't be uploaded in time.
- Floating vehicle can't move to some area when traffic congestion happens in these road segment. And the traffic information will not be collected to traffic control center.

III. System Analysis and Description

In this section, we will propose a new hybrid WSN data collection (HWDC) algorithm based on floating vehicle and hierarchical WSN to solve the disadvantages of hierarchical data collection algorithm analyzed in section II.

A. Requirement Analysis

Urban traffic information includes two categories baesd on time characteristic: static traffic information and dynamic traffic information [11]. The static traffic information includes roads and their infrastructures which will not vanish in the procedure of dealing with traffic information. The dynamic traffic information includes taffic events (such as traffic accident, abominable weather and road maintenance etc.) and taffic flow (such as speed of vehicle, lane occupancy rate, queue length etc.) which change all time of day. It is obvious that collecting dynamic real time traffic information is the key of ITS.

1) The characteristic of urban dynamic traffic information

The urban dynamic traffic information may be generally classified into periodic traffic information and nonperiodic traffic information. For example, the vertex of every day traffic flow always appears in the time of on duty and off duty. And traffic events stochastically happen without periodicity. The periodic traffic information is collected on fixed interval that can save the system resouce (ie., energy of sensor node) and prolong the life span of network. When the traffic flow state changes sharp or a traffic event happens, the traffic information must be collected to urban traffic control center in time, And then, urban traffic control center analyzes and issues these information to drivers and passengers in no time. Only in this way can the urban road be clear.

2) The infrastructure of urban traffic

Urban traffic infrastructure include the vehicles (such as taxies, buses etc.) running on the road except road and its affiliated infrastructure (such as road lamp, traffic light, traffic flow guidance information board etc.). The relation of vehicle and road & infrastructures is as illustrated in Figure 2 [12].

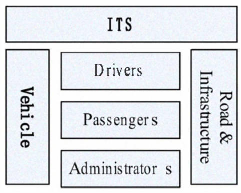

Figure 2. The relation among vehicle, road & infrastructure in ITS

Figure 2 shows the composition of urban ITS and the development directions to improve the efficiency of urban ITS. The urban ITS includes three improtant communication systems: vehicle to vehicle (marked as V2V), vehicle to infrastructure (marked as V2I or I2V) and infrastructure to infrastructure (marked as is I2I).

B. Hybrid WSN Data Collection Algorithm

Urban ITS network is enormous, which requires vast longevity sensor nodes to cover the urban road. Figure 3 shows the three-tiered network architecture of hybrid WSN data collection algorithm that we proposed, which includes roadside sensor nodes (marked as RSN), vehicle sensor nodes (marked as VSN), intersection control units (marked as ICU) ,basestation access points (marked as BAP) and urban traffic control center (marked as TCC). The bottom tier consists of vast RSNs deployed on two sides of roads and VSNs deployed on floating vehicles. The middle tier consists of many ICUs deployed on crossroad. And the top tier consists of some BAPs and an urban TCC. It is obvious that this architecture based onWSN has notable predominance compared to video cameras and inductive loops connected by wired fashion in terms of maintenance convenience, application agility and cost of system etc.

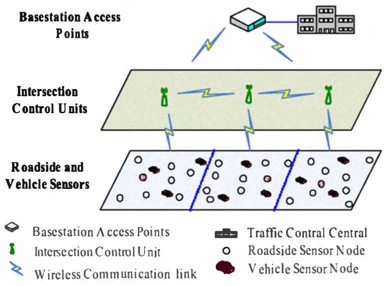

Figure 3. The architecture of hybrid WSN data collection algorithm

1) The Tier of Roadside and Vehicle Sensor Nodes

The deployment of the bottom tier is as shown in Figure 4. RSNs are deployed along a road, VSNs are installed on running vehicles (such as buses, taxies etc.) and every intersection is installed of an ICU which can control the traffic lights and traffic guidance information board.

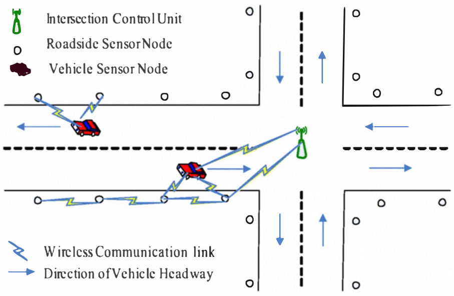

Figure 4. The deployment of roadside & vehicle sensor nodes

In the figure 4, RSNs are used to sense the real time road traffic state infromation such as vehicle speed, magnitude of traffic flow, lane occupancy rate, queue length, traffic congestion state, traffic accident and weather information, etc. and These nodes can provide exact location function to vehicles that running on the roadway. RSN has restricted computing ability, storage ability and battery power supplies. Especially, the energy can not be recharged. So it is important to design an energy efficient algorithm for sensors to prolong the life span of WSN. ICU and BAP have abundant computing and storage resource compared to RSN and VSN. Furtehmore, the energy of BAP, ICU and VSN can be recharged in time.

VSNs collect data continuously from RSNs during they running on the roadway. When VSNs pass through an ICU, they relay the data to it. And then, the ICU analyzes the data and control traffic lights, update traffic guidance information boards and issue other services to users (such as passengers and drivers). Lastly, the data is uploaded to urban traffic control center through BAPs and form overall analysis and decision-making.

The traffic information data packet generated by RSN is cached in its memory to wait the VSN arrival. When any one VSN arrives the RSN, the RSN relays data packet to the VSN and free its memory simultaneously. The data packet of urban dynamic traffic information is as illustrated in Figure 5. In the figure, ID denotes the identifiable number of RSN; P denotes the position of RSN; E denotes the residual energy of RSN; TTL denotes the longest waiting time of data packet in RSN memory; Type denotes the type of data packet, for example, periodic traffic flow, traffic accident, traffic congestion and other urgency events, etc.; Data denotes effective data sensed from VSNs in monitoring field.

ID	P	E	TTL	Type	Data

Figure 5. Data packet of urban dynamic traffic information

On the whole, urban traffic information may be classified into urgency data and non-urgency data according to the analysis in section III.A.1. The non-urgency data accounts for the overwhelming majority of the total dynamic traffic data of the urban, while urgency data is very little. So we use different data collection approachs to deal with urgency data and non-urgency data by setting TTL field and Type field in data packet, which can improve the algorithm performance in terms of delay, energy, self-adaptation and robustness etc. The procedure of data collection in bottom tier is as shown in Figure 6.

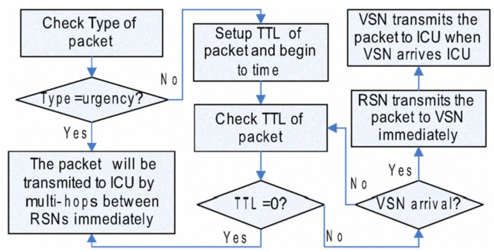

Figure 6. The data delivery flow chart of roadside & vehicle sensor nodes

In the figure 6, If one data packet is urgency events, the packet will be transmited through multihop mode on RSNs to ICU directly. or else, The packet will wait a set time in the memory of RSN until a VSN arrives. If no VSN arrives in the set time, the packet will use multihop mode on RSNs to ICU too. Furthermore, when two or more VSNs arrive the same RSN in a short time, the RSN will adopt the strategy of first arrival fisrt service.

2) The Tier of Intersection Control Units

ICU is responsible to collect the data packet from adjoining roads and exchange data with neighboring ICUs. The ICU analyzes all data in its memory to form control decision which is used to update the traffic guidance information boards and control traffic lights. The deployment of ICUs is as shown in Figure 7. The ICUs of the whole city form a middle tier network. There are two communication fashions between ICUs in the middle tier. the one is using VSNs to relay data packet, and the other is that ICUs are equipped with IEEE 802.16 (WiMAX) network interface to exchange the traffic information with neighboring ICUs directly. The WiMAX network interface provides a wide range (3-5km) of communication and a data rate of 30Mbps [13]. If the distance between ICUs is bigger than five kilometers, we can use VSNs to relay data packet or intall relay equipments on the road segment between these ICUs.

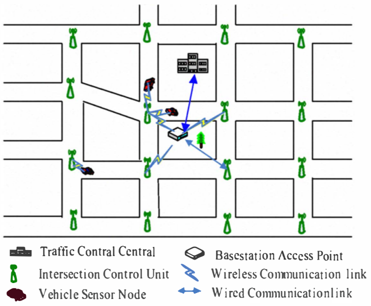

Figure 7. The deployment of intersection control units

3) The Tier of Basestation Access Points

According to the city size, we can set up several BAPs to collect data packets from ICUs. In order to get high quality communication, urban traffic control center connects every BAP directly with wired fashion.

IV. Performance Analysis and Evaluation

This section presents a performance comparison of the proposed HWDC algorithm with the TBD [10] algorithm. The performance of the these algorithms is analyzed with different parameters of the average data packet delay, data loss rate and the number of vehicle arrival per hour.

A. Average Data Packet Delay

The average data delay is referred to the duration from data generation to data reception by a BAP node. For the sake of simply analysis, the WiMAX network interface is used to exchange the traffic data packet from ICU to BAP in HWDC algorithm. The impact of the number of vehicle arrival per hour (marked as N) on average data delay is evaluated in Figure 8. In the figure, with the increasing of N, the average data packet delay decrease significantly. And the longest data packet delay of HWDC algorithm will not exceed the value of TTL of the data packet (The TTL can be setup according to the demand of applcation), which effectively ensure the urgency traffic data packet (such as traffic accident, traffic jam and other sharp changes of traffic flow) to be uploaded to urban TCC in time.

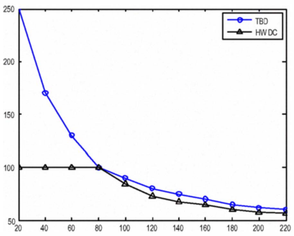

Figure 8. Impact of the number of vehicle arrival per hour on delay

B. Data Packet Loss Rate

Data packet loss rate is defined as the ratio of the number of data lost to the total amount of data generated. Figure 9 shows data packet loss rate for simulations run with both HWDC algorithm and TBD algorithm. In the figure, data packet loss rates decrease with the increasing N in TBD algorithm. But the data packet rate of the HWDC algorithm is zero all the time when the TTL of the data packet has a appropriate value. The data packet loss rate of TBD algorithm decreases at a higher rate as the N increases range from 0 to 60. and it's data packet loss rate is zero all the time when N is beyond 60. The reason is that TBD algorithm entirely depends on floating vehicles (that is equal to VSNs of HWDC algorithm) to collect traffic information. Only the number of floating vehicle arrival per hour is big enough can the data packet loss rate of TBD algorithm be zero.

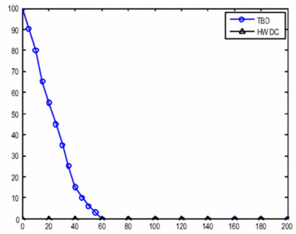

Figure 9. Impact of the number of vehicle arrival per hour on data packet loss rate

V. Conclusion

WSN and floating vehicle technologies were used in urban ITS at the same time, which realized urban dynamic traffic information collection algorithm. The algorithm is able to enhance the capabilities of gathering, managing, analyzing and issuing of urban road real time traffic information, and improve cooperative control capability of different road segment to satisfy synthesis information requirement of users (such as dirvers and passengers etc.). The HWDC algorithm maked fully use of these advantages of static WSN technologies and floating vehicle technologies, which provided approving performance in terms of data packet loss rate, and assured that urgency data packet was uploaded in time.

In the future, we plan to make further investigation of the impact of different parameters (such as the urban scale, the road length, the speed of VSN, the number of VSN etc.) on system performance. And study the network cooperating work model to further improve performance of urban ITS.

Acknowledgment

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