SURVEY ON APPLICATION OF WIRELESS SENSOR NETWORKS FOR TRAFFIC MONITORING

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Abstract: Wireless sensor networks are new integrative technologies arising from the development of wireless communication and tiny sensors. With the reduction of power consumption and cost of instruments and maintenances, it's ready to install over large-scale traffic areas and monitor roads in a much fine way, which is certain to bring some breakthroughs in the field of traffic monitoring. Surveying the technologies of vehicle detecting nodes, communication networks, traffic forecasting algorithms and architecture, this paper gives a full view of the application of wireless sensor networks in traffic monitoring systems. The key technologies and future development trends are also analyzed in details.
Key words: *vehicle detection, traffic monitor, wireless sensor network*

1 Introduction

Essentially, traffic systems are distributed parameter systems. The traffic parameters on the different sections of the road are not uniform, because the propagation of traffic flow is vulnerable to the influence of drivers' personality and skill, pedestrians crossing the roads, intersections of minor roads, accidents and so on. The precision and robustness of traditional traffic forecasting methods cannot meet the requirements of developing traffic control and guidance technologies.

Wireless sensor networks (WSN) are new integrative technologies arising from the development of wireless communication and tiny sensors. WSN is a kind of monitoring networks consisting of a large number of low-cost, power-saving, highly integrative and self-organized sensor nodes and network coordinators. WSNs own broad and valuable application outlook including military, urban management, biomedical treatment, environmental monitoring and remote monitoring of dangerous areas.

WSNs installed on roads in a sweeping manner can not only obtain the traffic flow parameters of the entries and exits of intersections, but also of the forks, crosswalks, bus stations and other special places. Therefore, with WSNs covering road networks over a great area, the globe traffic information can be observed in details in the traffic monitoring center. This trend will certainly bring great breakthroughs in the traffic monitoring technologies. Many researchers have paid close attention to this hot field. Ding (2004) and Knaian (2000) have already produced relevant prototypes. Some companies also produce corresponding products, such as Nu-metrics' GROUDHOG, Sensys' VSN240 and SenSource's SS-MS30.

At present, there have been in-depth researches in vehicle detecting WSN nodes, which are surveyed in this paper. At the same time, current relevant works on communication network, traffic forecasting algorithms and architecture are also reviewed, for the sake of constructing an integrate traffic monitoring WSN.

2 Vehicle Detecting WSN Nodes

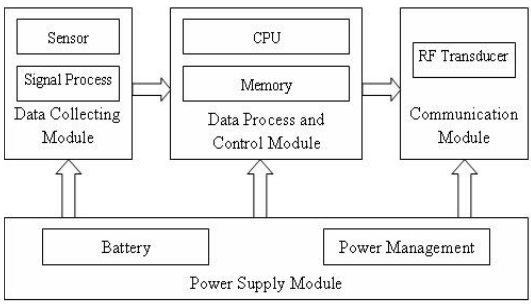

Figure 1. The architecture of WSN nodes

WSNs consist of a large number of WSN nodes with the same or different functions. Each node is composed of a data collecting module with sensors and signal processing unit, a data processing and control module with CPU and memory, a communication module with RF transducers, and a power supply module (Figure 1). These nodes act as data collectors, communication coordinators and network center in WSNs (Ma,2004).

Relative to traditional wireless networks and sensors, WSN nodes are low-cost, power-saving, highly integrative, robust and capable of forming high-density and self-organized network. Measuring traffic flow is firstly based on detecting vehicles. WSN nodes can count vehicles and detect their speed, direction and types, which are aggregated and processed on the scale of time and space. Therefore, the distributed parameters of traffic flows can be predicted.

There are some more requirements on the WSN nodes deployed for traffic monitor.

(1) High reliability. Faults of traffic monitoring may disable traffic management and result in great loss and safety problems.

(2) Long-time service. The vehicle detecting nodes need to be installed on road surface, so the complexity and cost of installment and maintenance are higher than common WSN nodes.

(3) Highly real-time. In the traffic control and guidance systems, control parameters and guidance information are optimized and adjusted according to the results from the short-time traffic forecast. Therefore, it's necessary for the whole WSN to collecting, aggregating and processing data in one or several minutes.

Vehicle detecting technologies usually rely on the effects of acoustics, optics, press, geomagnetism and radio reflection (Mimbela,2000). In view of the requirements on reliability, low power and sampling speed, sensors based on acoustics, pressure hose and geomagnetism are usually applied in the case of WSN. However, sound is vulnerable to be disturbed, and the pressure hose is difficult to install and maintain, so a kind of geomagnetic sensors, called Anisotropic Magnetoresistive (AMR), are the most widely used components (Wang, 2004). AMR is a low-power, highly integrative and highly precise chip (Caruso,1999), which has already been adopted in the products mentioned above.

Because radio transmissions usually consume a large proportion of power supplied by batteries, it's necessary to choose the low-power RF chips with programmable power management.

3 Communication Network

The low-power requirement of WSN nodes renders that WSNs can only depend on short-range communication, which is a big challenge for networking. Low-power RF chips with programmable power management can reduce the power consumption of radio transmissions for each time at the hardware level, but the algorithms of channel contending and network routing are the key factors to reduce the power consumption of the whole network, and are two hot research fields too.

The state-of-art algorithms of channel contending and network routing exhibit respective traits, because WSN is strongly application-oriented technology. A protocol may operate very well in some instances, but very poorly in other instances. On the other hand, in order to realize interconnection between different kinds of WSN nodes, there must be certain standards on physic layer, data link layer, network layer and even other upper layers. Of course, these standards must cover primary kinds of applications, like the TCP/IP protocols of internet. The 802.15.4 standard and ZigBee protocols are dedicated to this aim. ZigBee is a power-saving, reliable, low-cost, large-scale and safe short-range wireless communication protocol.

Since vehicle detecting nodes are installed on roads and keep working for long time with batteries supplying power, they usually act as reduced function devices (RFD) in the ZigBee protocols, which only communicate with the repeaters and don't join routing that may increase power consumption notably. The repeaters supplied by DC, solar or high-power batteries can acts as full function devices (FFD) in the ZigBee protocols to perform frequent data transmissions as ad hoc repeaters or wire/wireless bridges.

4 Traffic Forecasting Algorithms

According to the number of detecting points, traffic forecasting algorithms can be classified as single-point, double-point and multi-point. In the traditional traffic control and guidance systems, single-point algorithms are the most commonly used, which deduce the future flow variation on some relevant points depending on one observing point. Double-point and multi-point forecasting algorithms are much more complex to realize than single-point forecasting algorithms, and are usually used to detect traffic events.

When applying WSN to traffic monitoring, it's necessary to design multi-point and multi-function traffic forecasting algorithms to match the data aggregation in the WSN. 'multi-point' means that aggregating and fusing traffic flow data from many WSN nodes to obtain more prolific and precise results. 'multi-function' means that various kinds of traffic information can be sampled and forecasted in the same one WSN.

Single-point forecasting algorithms have the longest history and rich outcomes. There are many kinds of models based on statistics, such as history average model, linear regression model, time series model, Kalman filter model, Markov model, and maximum likelihood model (Liu,2000). Besides, there are some new methods as wavelet analysis model and neural network model. However, single-point algorithms usually have low precision, respond slowly to traffic events and are vulnerable to interferes.

Double-point and multi-point algorithms can notably improve the forecast precision and response speed to traffic events. On account of the high cost and complexity, the research and application of double-point and multi-point forecasting systems are less than single-point algorithms.

Essentially, there exists a study procedure from historical data both in statistical methods and in intelligent methods. Multi-point forecasting algorithms depend on sample data from multiple positions, have strong self-study ability and even have redundant sample data to study and calibrate.

5 Architecture

There are various choices to construct a traffic monitoring WSN, such as the ad hoc self-organized network, the mixed mode of short-range and long-range wireless communication and the hybrid mode of wire/wireless communication.

The ad hoc self-organized network is a flat and multi-hop wireless communication network. Allowing for bandwidth, response speed and cost, it's obviously infeasible to transfer traffic data from the whole city to the traffic monitor center totally through an ad hoc network. The mixed mode of short-range and long-range wireless communications has the advantages of flexibility and low cost, which may become a promising solution when the wireless broadband technologies become mature. The hybrid mode of wire/wireless communication adds short-range wireless communications to the present communication network in the traffic control and guidance system. The hybrid mode takes full advantage of current investment and validated performance by long-term run. It has the lowest cost and very reliable, and it's the most acceptant solution at present. (Yuan,2006)

The hybrid mode consists of WSNs and present network, and can be divided to three layers. The top layer is city layer, consisting of traffic monitoring center and stations, which are connected by optic fiber cables to form the backbone of traffic information network. The middle layer is region layer, consisting of traffic information cabinets installed at intersections, roads and residential subdistricts, which are connected by optic fibers or cables to form subnets. The bottom layer is field layer, consisting of the WSN nodes on roads, the ad hoc nodes beside roads and the WSN nodes distributed around subdistricts, which are connected by short-range wireless communication to form terminal networks.

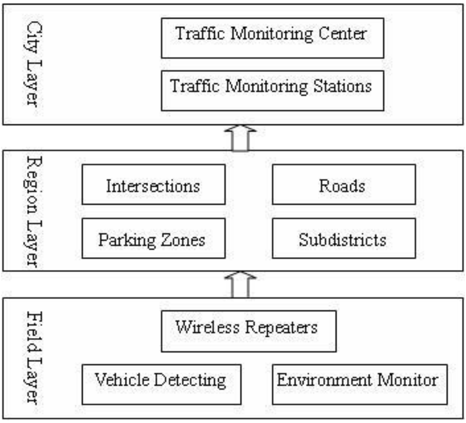

Figure 2. The architecture of the hybrid mode

Figure 2 shows that the top and middle layers of the architecture are consistent to present traffic information network. The bottom layer makes up of WSNs, which are very flexible.

6 Conclusion

With the rapid developing WSN technologies, all kinds of information of the physic world around us will be transferred to the present information system at a fine level and with high speed. As a result, the urban traffic network with distributed parameters will become more measurable and controllable. This paper surveys the key technical problems relevant to this application proposition. A feasible systematic solution is proposed on the basis of comparing various solutions.

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