Proceedings of the 6th World Congress on Intelligent Control
and Automation, June 21 - 23, 2006, Dalian, China

Modeling and Simulating Wireless Sensor Transportation Monitoring Network*

Lingyun Yuan[1,2] and Yunlong Zhu[1]
[1] *Shenyang Institute of Automation, Chinese Academy of Sciences, Shenyang*
[2] *Graduate school of the Chinese Academy of Sciences, Beijing*
{wxcyly, ylzhu}@sia.cn

***Abstract* - We have proposed a new wireless transportation monitoring scheme based on wireless sensor network (WSN), namely wireless sensor transportation monitoring network (WSTMN), which differs from some old wired schemes greatly. As a novel information acquisition technology, WSN has many advantages that help to improve the performance of transportation monitoring system. We simulated WSTMN in NS2, in which some new functions are extended. Some simulating experiments are designed to optimize these important parameters including energy consumption of sensor nodes, network density and data sensing rate, so as to optimize the WSTMN model. The WSTMN system is proven to be feasible with low system cost, low energy consumption and high efficiency. It prefers obviously to the old systems on the aspects of real-time control, enormous data computation and immunity to disturbances.**

Index Terms* - *Wireless sensor network. Intelligent transportation monitoring system. Network simulation. NS2.

Ⅰ. INTRODUCTION

Recent advances in data processing, storage and communication technologies have accelerated the development of wireless sensor network (WSN). Many successful projects have been established and accomplished, such as Smart Dust [1], uAMP（u-Adaptive Multi-domain Power aware Sensor）[2] and WINS (Wireless Integrated Network Sensors) [3]. And WSN has been applied to many areas extending to commerce and industry fields from the military field, such as environment monitoring, weather monitoring, tactical surveillance, and intelligent transportation monitoring. We mainly focus on intelligent transportation monitoring system based on wireless sensor network.

Due to the physical environments and the system costs, the system model can not be applied to highway monitoring before validated effective. The field tests and computer simulation contribute to our project. The parameters can be tested and evaluated in system simulation, which can solve network architecture, operating system, network protocols and distributing processing in wireless sensor networks. Moreover, noise, vibration and some other nondeterministic factors are considered. The whole application process is implemented in system simulation.

The highway intelligent transportation monitoring system based on wireless sensor network [4][5] is self-organizing and distributing ,which can monitor and control highway in real-time. Its system architecture and mechanism [4] were presented, and some system functions such as vehicle's speed detection and location [5] were implemented. But the performance evaluation and optimization of system are difficult to implement in field tests. In this paper, wireless sensor transportation monitoring network (WSTMN) model is put forward. The model is simulated in NS2, which is extended to support wireless sensor network. Some important parameters such as nodes energy consumption and network layout are simulated, with which the model optimization and system evaluation are achieved.

The rest of this paper is organized as follows: Section 2 builds up wireless sensor transportation monitoring network simulation model. Section 3 extends the NS2 to support wireless sensor network. And in the section 4, wireless sensor transportation monitoring network model is simulated and system simulation performance is analyzed. Finally, some conclusions are presented.

Ⅱ.WIRELESS SENSOR TRANSPORTATION MONITORING NETWORK SIMULATION MODEL

A. The Wireless Sensor Network Node Simulation Model

In a typical wireless sensor network, sensors monitor a specific environment such as airport, battlefield or highway, and send reports to a sink node. There are different types of signals about sound, light, magnet and seismic. Signals are generated by target nodes (monitoring targets). Hence, a wireless sensor network simulation environment consists of three parts: target nodes, sensor nodes and sink nodes. Sensor nodes detect the signals coming from target nodes and forward the necessary data to the sink nodes. Finally, a sink node receives data collected by sensors.

Since the nature of signal propagation between target nodes and sensor nodes is absolutely different from that between sensor nodes and sink nodes, two different modes for channels and protocol stacks are necessary [6]. Namely, a sensor node is equipped with a sensor protocol stack and a wireless network protocol stack. The former enables it to capture signals generated by target nodes through a sensor channel, and the latter enables it to send reports to the sink nodes through a wireless channel. This operation is illustrated in Fig 1. The alliance of the sensor protocol stack and the wireless network protocol stack is usually called the sensor function model.

* This work is supported by the National Natural Science Foundation, China (No. 70431003) and the National Basic Research Program, China (2002CB312204)

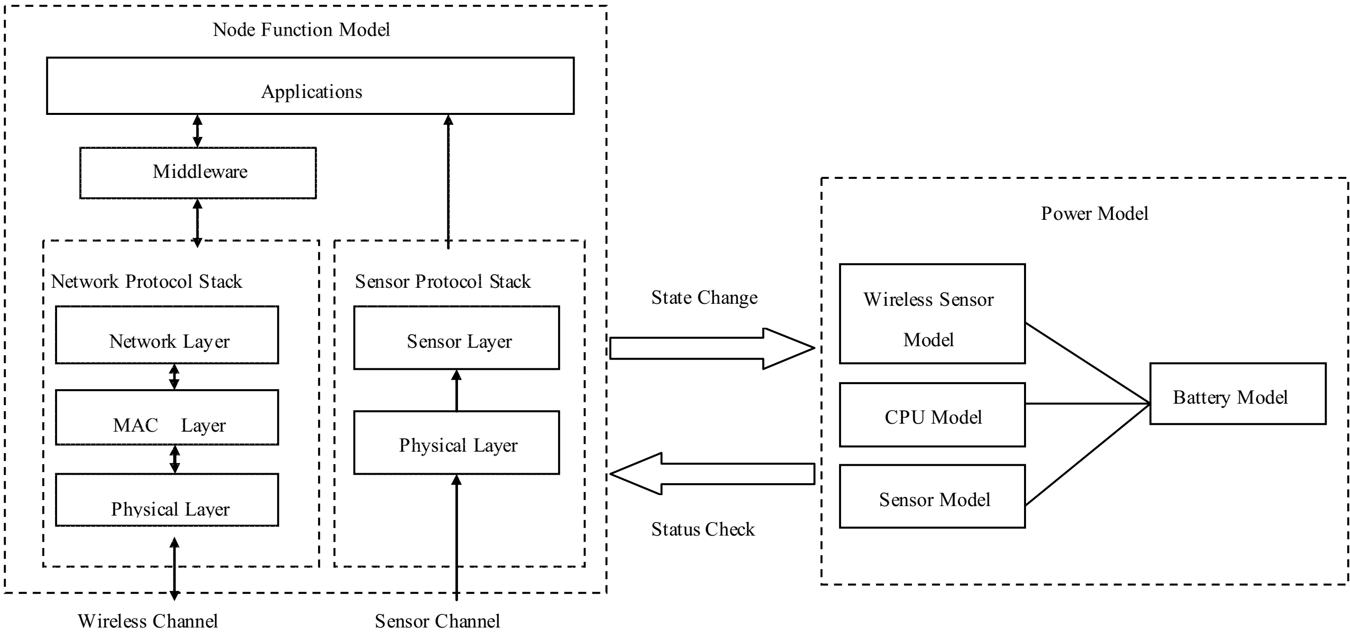

Fig.1. Wireless sensor network node simulation model

A sensor node also has a power model that embodies the energy-producing components and the energy-consuming components. The power model enables a sensor to fulfill the functions of the sensor function model. The whole function model of wireless sensor network nodes is illustrated in Fig 1.

B. Wireless Sensor Transportation Monitoring Network Simulation Model

The simulation model is based on wireless sensor transportation monitoring system [4], which consists of five parts: wireless sensor network system, base station, monitoring center, information distributing system and receiving devices on vehicles. Wireless sensor network system locating in the road surface of highway communicates by radio, and wired link connects base station and monitoring center due to communicating range and high data rate of wireless sensor network.

According to the above-mentioned, the mixed wireless and wired network model has been built up. Because of the differences in node deployment and mechanism between the two kinds of network, the gateway (base station) nodes are essential. When the node in wired network needs to communicate with those in wireless network, the signal will be sent to gateway at first, by which then be broadcast to wireless network. And the nodes in wireless network will receive and process the signal. In our system, wireless sensor network needs to detect and listen to highway in real time. The monitoring center distributes the control information to vehicles or information distributing system. And base stations are responsible for forwarding and broadcasting. Thus, there are five kinds of nodes in the wireless sensor transportation monitoring network simulation model, which are (1) monitoring center node, (2) gateway nodes, (3) sink nodes, (4) sensor nodes and (5) target nodes. And the WSTMN model is shown in Fig.2.

C. Wireless Sensor Network Layout

The wireless sensor transportation monitoring network model has been built up in section *B*, one of the most important problems of which is wireless sensor network layout and nodes density optimization. They will influence network security, system cost, data rate and some other performances directly. Network coverage and connectivity are important parameters what should be considered when deployed. It is essential to ensure that nodes can communicate with each other in their communicating range $R_{communicating}$, and sense any signals in their sensing range $R_{sensing}$. According to this, the coverage of wireless sensor transportation monitoring network is defined as (1) after we have considered the characteristics of highway.

$$CVG = \frac{\bigcup_{i=1}^{n} R^2_{sensing}(x_i, y_i)}{Area}. \tag{1}$$

Where $R^2_{sensing}(x_i, y_i)$ is the covered scale of node i, and Area is monitoring area. The coverage is equal to the area of the union of the disks of radius $R_{sensing}$ centered at each connected sensor. $CVG_{threshold}$ is the threshold of CVG, which can vary according to the demands of network. In this paper, it is assumed that $R_{sensing}$ of all sensors are identical. So the number of network nodes is defined as (2):

$$N_{\min} \geq \frac{Area}{\pi R^2_{sensing}} \times k . \tag{2}$$

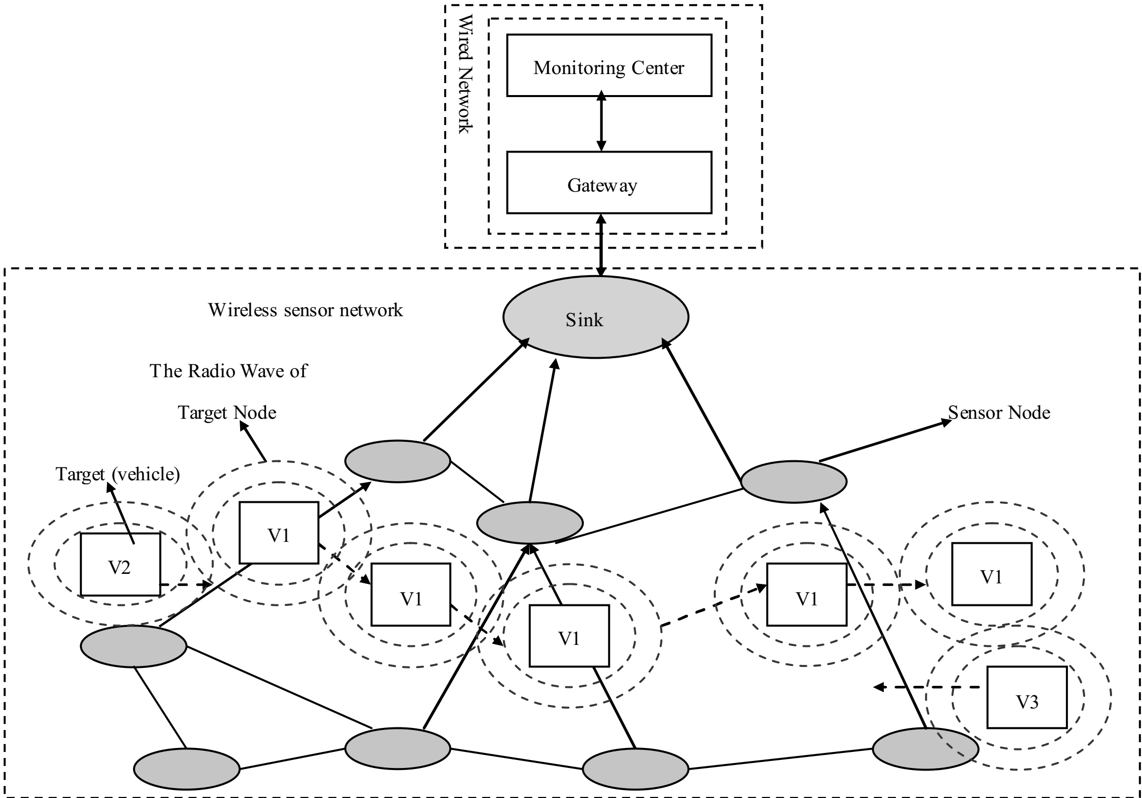

Fig.2. Wireless sensor transportation monitoring network simulation model

Where N_{min} is the minimum number of network nodes, Area and $R_{sensing}$ are the same to (1), and k is coverage multi plicity (k>=1). Due to the standardization of it, highway can be regarded as the union of many rectangles A_i (i=1, 2,…, n).So N_{min} can be modified as (3):

$$N_{\min} \geq \frac{\bigcup_{i=1}^{n} A_i}{\pi R_{sensing}^2} \times k \, . \tag{3}$$

In section Ⅳ, network model is simulated, and these parameters will be set to be different values according to different system demands, by which the best N_{min} will be found.

Ⅲ.THE EXTENSIBILITY FOR WIRELESS SENSOR NETWORK IN NS2

NS2 [7] is a discrete event simulator targeted at network research. NS2 provides substantial support for simulation of TCP, routing, and multicast protocols over wired and wireless networks. The wireless Ad-hoc network model based on energy constraints is implemented. Mobile network in NS2 has provided supports for applications and protocols of application layer, transport layer, data link layer, and physical layer. And the nodes movement and energy-constraints are included in wireless model. But NS2 doesn't provide support for physical phenomenon (e.g., vehicles, creatures, etc.) simulation and correlative processing protocols. On the basis of the above-mentioned, we add new functions to support the simulation of wireless sensor network and simulate wireless sensor transportation monitoring network system.

1) Simulating phenomenon. Sensors mainly sense physical signals, and collect data. Thus, the physical signals need to be simulated Tin wireless sensor network simulation. But NS2 doesn't include phenomenon simulation. This paper extends NS2 to involve more functions such as phenomenon detecting, phenomenon awaking and sensor applications.

The phenomenon (phenom) channel [8] is built up in NS2, in which physical signals are simulated with broadcasting packets. The broadcasting range is a set of sensor nodes, which can receive phenom packets coming from the phenom channel. And it's fit for any wireless broadcast model such as Free Space, Two-Ray-Ground and Shadowing. In general, the broadcast model is circular, which can also be set according to the transmitting range.

2) Adding PHENOM protocols. Most protocols can be simulated in NS2 such as DODV, DSR, and AODV, but these protocols are not competent for broadcasting and transmitting phenom packets, which lead to the emergence of a special protocol for phenom packets, namely, phenom protocol. The processing for physical signals such as light, sound, temperature and magnet are included in phenom protocol. Our project mainly focuses on the simulation for sound and magnet signals. Phenom protocol broadcasts packets with a frequency what is set beforehand, as soon as they listen to phenom packets, nodes in phenom channel will receive these packets and trigger the relevant sensor applications.

3) Modifying AODV. Due to short distance and multi-hop of wireless sensor network, AODV is regarded as the routing protocol, which is responsible for forwarding phenomenon packets. In wireless sensor network applications, the power of sensors cannot be updated, so energy saving is very important, which is also necessary in simulation implementation. AODV protocol has been modified according to our application demand. One of modifications is the extension for energy model in NS2. The extended model is based on the communicating distance of WSTMN and Two-Ray-Ground [9] propagation model. The Two-Ray-Ground Propagation model is based on (4):

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4}. \quad (4)$$

Where d is the distance between transmitter and receiver, $P_r(d)$ is receiving energy consumption when the distance d is between sender and receiver, P_t is transmitting energy consumption, G_t is transmitting antenna gain, G_r is receiving antenna gain., h_t is the height of transmitting antenna, and h_r is the height of receiving antenna.

Ⅳ.THE SIMULATION RESULTS AND PERFORMANCE ANALYSIS

In this simulation, G_t and G_r are both set to be 1.0. h_t and h_r are set to be 0.2. From above (4), P_t and $P_r(d)$ can be computed. There are three target nodes (monitoring targets) that are used to simulate vehicles in highway, one sink node, one gateway node and one monitoring center node. And the monitoring scale is set to be 1000×100.

The colors are used to label the change of states. The initial state of sensor nodes is labeled with green. Target nodes broadcast packets periodically. When sensor nodes sense the signal coming from target nodes, they will change to working state from idle state, which is labeled with red. After target nodes move out of monitoring scale, sensor nodes will turn back to idle state. Three target nodes move to monitoring scale with different beginning time and speeds in the simulation. The whole simulation process can be recurred in NAM.

A．Energy Consumption Analysis

Wireless sensor networks are generally applied to monitor remote and hazardous areas. The power of sensors mainly comes from battery. It is difficult to update. So minimizing energy consumption and maximizing the system lifetime has been a major design goal for wireless sensor networks, which is also one of the most important goals in highway wireless sensor transportation monitoring network system.

We assumed all sensors have the same sensing range and communicating range. $P_{initeng}$ is the initial energy of every sensor node. $P_{sensing}$ is the energy consumption that sensor senses signals in every time. P_t and P_r are energy consumption that sensor transmits and receives signals in every time.

Wireless RF transmitter/receiver consumes most of energy in sensor node. When d = 100m, 0.00028J will be consumed by transmitting 1 bit, which is equal to that the ATMegal128L processor executes 65 instructions. So the tradeoff should be considered between communicating and processing. AODV protocol based on energy efficiency is used in our system. Fig.3 (1) shows energy consumption of node 5, 12, 13 when network density is 20. The $P_{initeng}$ is going to decrease along with sensing, transmitting and forwarding packets. When $P_{initeng}$ is less than $P_{threshold}$, the node will be dead, which is illustrated by blue curve. And the network will be reorganized with the remainder nodes. But if CVG is less than $CVG_{threshold}$, the dead nodes will influence many operations of network. Therefore, it's very important to balance energy consumption and network density. Fig.3 (2) shows how the network density influences nodes energy consumption. The results indicate the network of 20 nodes is the most optimized in this monitoring area when all sensor nodes have the same $R_{sensing}$.

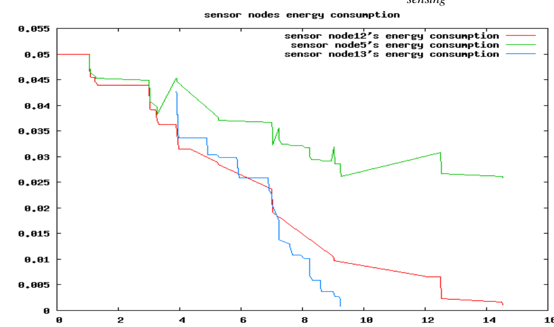

Fig.3（1）.The energy consumption of nodes

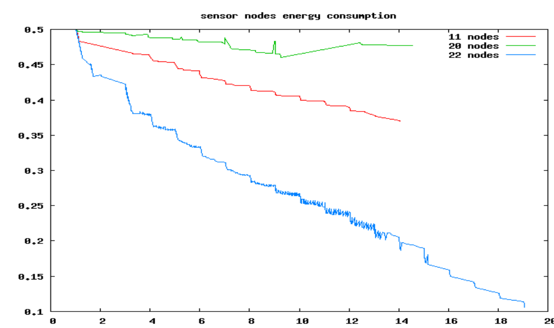

Fig.3 (2) .Network density VS nodes consumption

B. Data Integrality Analysis

In wireless sensor network, the network density is one of the most important parameters. High density is a guarantee that the target nodes can be detected in real time and integrallty. When the network density is 20, we have the statistic data on the transmitting packets and the receiving packets for target nodes, which is shown in Table Ⅰ. The table 1 indicates that the signals of target nodes can be detected by one or multiple sensors. The average sensing rate is up to 1.0. The redundancy ensures that the data are quite integrated.

The relation between the network density and the average sensing rate is described in Fig. 4. With the increasing of node density, the sensing rate is linearly rising. Higher density can effectively improve monitoring capability, and reduce or eliminate monitoring blind zone. Due to the system cost and other factors, we select the most suitable value for the actual system under conditions of $CVG_{threshold}$ and redundancy, which can not only provide a monitoring capability without blind zone, but also minimize the cost of system. The results indicate 20 is the most suitable value in 1000×100.

TABLE Ⅰ

THE SENSING RATE OF WIRELESS SENSOR NETWORK

Target Node	Transmitted Packets	Received packets	Sensing Rate
v1	212	247	1．165094
v2	211	209	0．990521
v3	212	565	2．665094

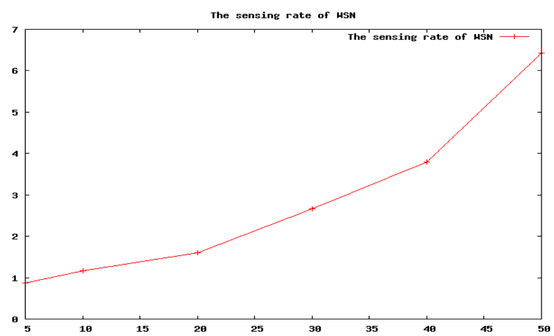

Fig.4. Network density VS average sensing rate

C. *System Performance Optimization*

According to the above analysis, we optimize the network model by modifying N_{min}, and find the optimal energy-aware scheduling.

1) According to standardization of highway, the maximum width is set to be 100m, which is involved in sensing range of sensors. After data rate is filled, system cost and network deployment are considered. The N_{min} of WSTMN is modified as (5):

$$N_{\min} \geq k \times \frac{l}{d} \; . \tag{5}$$

Where k is coverage multiplicity, l is the length of highway, and d is communicating range of sensors.

2) In order to save energy, it's very essential to find an appropriate energy-aware strategy. The working-idling mode in this paper is not the most appropriate. Event-driven nodes scheduling mode will be used to replace of working-idling mode. If there is no signal in sensor nodes' period or other nodes can sense that signal, the nodes will be shut down. Event-driven nodes scheduling mode will be one of our future works.

Ⅴ. CONCLUSIONS

In this paper wireless sensor transportation monitoring network model has been put forward. On the basis of existing components of NS2, we extend some new functions such as phenomenon detecting, phenomenon awaking and sensor applications to support wireless sensor network simulation, and simulate wireless sensor transportation monitoring network. The energy consumption of sensor nodes, network density and some other parameters are analyzed. The WSTMN system is proven to be feasible with low system cost, low energy consumption and high efficiency. In future work, we will do more work on WSTMN, in which event-driven nodes scheduling will be implemented to save more energy. And we will construct and perform the actual system based on WSTMN in Shenyang-Dalian highway. The application of WSTMN will remarkably improve the development of transportation and bring out tremendous economic benefits.

REFERENCES

[1] Pottie.G, Kaiser.W, "Wireless integrated network sensors," *A. Communications of the ACM [C]* 43 (5) (2000) 551-558.

[2] uAMPS(u-Adaptive Multi-domain Power aware Sensor), unpublished.

[3] Warneke.B, Liebowitz.B, Pister.K, "Smart dust: communicating with a cubic-millimeter computer," J. *IEEE Computer* (January 2001) 2-9.

[4] Yuan Lingyun, Zhu Yunlong, Qu Licheng, "Transportation monitoring system based on distributing wireless sensor network," J. *Computer Engineering*, in press.

[5] Yuan Lingyun, Zhu Yunlong, Qu Licheng, "Research on wireless sensor network applied in highway transportation monitoring system," *The Seventh International Conference on Eletronic Measurement and Instruments*, Vol (4): 336-340.2005.08.

[6] "A simulation framework for sensor networks in J-Sim," http://www.jsim.org/whitepapers/aca.htmlUU

[7] Kevin Fall, Kannan Varadhan, "The ns Manual," The VINT Project, 2003, http://www.isi.edu/nsnam/ns/doc/.

[8] Ian Downard, "Simulating sensor networks in NS-2," http://nrlsensorsim.pf.itd.nrl.navy.mil/

[9] T.S. Rappaport, "Wireless communications: principles and practice," Prentice-Hall, Inc, New Jersey, 1996.

[10]C.-F. Chiasserini and M. Garetto, "Modeling the performance of wireless sensor networks," *INFOCOM'04*, March 2004.

[11]Hsing-Jung Huang; Ting-Hao Chang, Shu-Yu Hu, Polly Huang, "Magnetic diffusion: Disseminating mission critical-data for dynamic sensor networks," *ACM/IEEE International Symposium on Modeling, Analysis and Simulation of Wireless and Mobile Systems (MSWiM 2005)*, Montreal, Qc. Canada, Oct. 2005

[12] N. Merizzi and W.F.S.Poehlman, "J-Sim and the demand for wireless sensor network simulation," CAS Technical Report #2005-03-SP.