http://ansinet.com/itj

ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 10 (4): 849-855, 2011
ISSN 1812-5638 / DOI: 10.3923/itj.2011.849.855

Hybrid Intelligent Monitoring Network Based on Ad hoc and Wireless Sensor Networks

[1,2]Hongyu Chu, [1]Zhijiang Xie and [2]Hong Jiang
[1]State Key Laboratory of Mechanical Transmission, Chongqing University, Chongqing, China
[2]College of Information Engineering, Southwest University of Science and Technology, Mianyang, China

Abstract: For the applications of certain dangerous situations, such as battle field monitoring or dangerous explosives scenes etc., a wireless intelligent monitoring system based on ad hoc and WSNs (Wireless Sensor Networks) is proposed and designed accordingly. Mobile nodes in the ad hoc are constituted by smart cars with positioning, communication and monitoring functions, while the nodes in the WSNs are achieved by using Bluetooth technology and the embedded system technology. To improve the route quality of communication nodes in sparse environments, a model for mobile wireless network based on chain formation is proposed. Meanwhile, a standby node strategy and a smart ferrying information method based on Q-learning are also put forward to improve network survivability. For the Bluetooth wireless sensor networks in small size, a single path networking method based on kindred tree is proposed and implemented to simplify the network structure, leading to an increase of reliability. The simulation shows the network has the feature of small packet drop rate and better throughput, while the experiment shows that the complex network can finish monitoring tasks satisfactorily.

Key words: Ad hoc, wireless sensor networks, chain formation model, ferrying information, Q-learning

INTRODUCTION

The information measurement in special occasions has been a focus, especially in certain dangerous applications, such as dangerous field detection of explosives scenes, battle field monitoring and nuclear radiation environment. Special environment is often free from fixed and mobile network coverage (Boppana and Su, 2010) where, the network measurement and control technology of motion is generally subject to some special requirements, such as unmanned operation, mobility, collaboration, reliability and security. In many cases, it is only allowed to use the temporary wireless self-organizing network for monitoring. How to solve the reliable data transmission is the key to wireless network monitoring.

Targeting at the reliable networking, simple routing management can be achieved with the help of address space and the establishment of the logical tree structure of the connectivity between nodes (Caleffi *et al*., 2007). Though simple and easy management of the routing process can be achieved, the structure is lack in ability to respond to movement and link failure. According to changes in signal strength, routing protocols based on signal strength can advance into the routing switch state to ensure the effectiveness of routing (Yan *et al*., 2008). Attributing to the popularity of the position system, it is becoming feasible for each node in the network to access their location information, while routing protocol based on the location information is of great robustness (Singh *et al*., 2007; Ghinita *et al*., 2010; Wu *et al*., 2010). As for broken communication links, processing methods include and Epedemic and its improvements (Jindal and Psounis, 2006; Matsuda and Takine, 2008), grouped nodes transmitting (Zhang *et al*., 2006) and ferrying information (Zhao *et al*., 2004). In Epedemic methods, the message copy is stored and diffused between nodes in the random motion to reach the destination. This is characterized by less required network knowledge, yet resources being seriously occupied, not suitable for this project where the nodes are smart. Grouped nodes transmitting mainly involves the use of nodes that move in a specific path to carry messages to the destination nodes, or the use of probabilistic methods to estimate the nodes that are most likely to transmit data. This method requires specific transport nodes, strongly focused in the application and more suitable for carrying information in the reservation line. Ferrying information can achieve the use of special nodes to carry data in the cases of network outages, but there is no reasonable constraint that is made on the choice of the ferry nodes. The characteristic of nonrandom routing model is using information ferry nodes whose trajectory is controllable and with the help of their mobility to transmit grouped data, while its expansibility is limited (Tariq *et al*., 2006). Practical applications, where limited nodes and harsh environment combined may cause communication interruption and how

Corresponding Author: Zhijiang Xie, State Key Laboratory of Mechanical Transmission ,Chongqing University, Chongqing, China

to make communication reliably is the problem to tackle. In this study, a reliable network with chain formation is proposed. Standby node and information ferrying methods are used to improve the network survivability performance and finally, an experimental system based on mobile ad hoc and WSNs is achieved for verification process.

OVERALL DESIGN

Considering the monitoring requirements of these special occasions, we propose to use remote computer as a console, let some mobile smart cars fleet into the monitoring area, part of which carrying the sensor gateway and other monitoring devices into the coverage area of the WSNs to collect and transmit sensor information. Without relying on any existing fixed facilities, ad hoc can set up temporary networks wherever instead. It is featured with flexibility in networking, convenience in capacity expansion and strong survivability, low maintenance and operating costs, wide coverage and so on (Chlamtac *et al*., 2003). Mobile smart car group adopts ad hoc networks. WSNs are highlighted in low-cost, small size and strong capabilities, allowed to be arranged in any hostile environment and special areas (Akyildiz *et al*., 2002; Culler *et al*., 2004) hence being used to complete the measurement, storage and transmission of the environmental parameters.

For ease of description, we call the mobile smart car as MIA (the mobile intelligent agent). Depending on its functions, the mobile agent is divided into two categories: (1) MIAT - mobile intelligent agent for task: it is equipped with many equipments, such as audio and video capture device, high-precision navigation device, Bluetooth gateway and other monitoring equipment, as shown in Fig. 2. (2) MIAR - mobile intelligent agent for relaying: Mainly acting as communications relay, which is equipped with navigation and wireless communications plus less equipments as shown in Fig. 3. A laptop is used as the Control Center (CC), from which task commands are issued. At the information exchange level, the mobile agent motion control system includes two networking structures: ad hoc and WSNs. From the control perspective, it has a multi-layer structure including interactive control, network control agent, agent cooperative control, self-control of smart agent and sensor monitoring. When it comes to the functional view, it integrates control function, cognitive function, messaging function, management function, interface function and interactive function.

The entire system structure is shown in Fig. 1. After commands are issued by the control center, the mobile agent for the task will set up mobile network to monitoring area, which collecting the information back to the control center and complete the monitoring task.

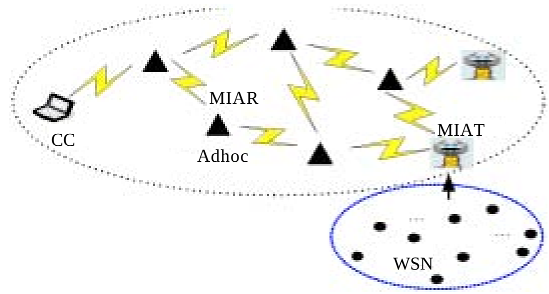

Fig. 1: Structure of the whole network; ( )--Stands for control center; (▲)--Stands for mobile agent for relaying; ( ) --Stands for the mobile agents for task. (●)-- Stands for wireless sensor network node, which is distributed in the fixed area, monitoring the environmental information continuously

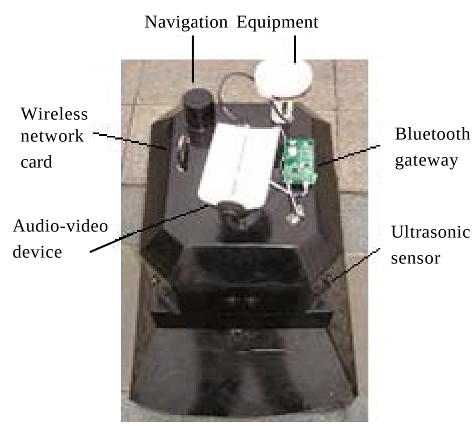

Fig. 2: Mobile intelligent agent for task

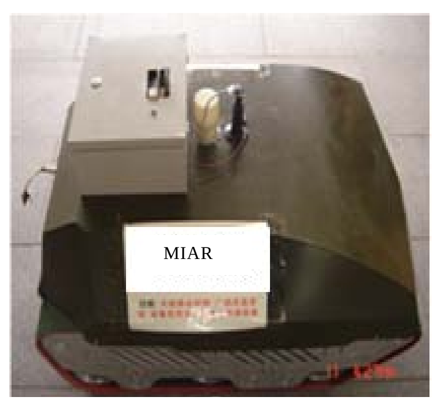

Fig. 3: Mobile intelligent agent for relaying

MOBILE NETWORK TECHNOLOGY IN CHAIN FORMATION

In sparse applications, the routing maintenance between nodes has been a difficult problem. Current major solutions may either be an increase in the number of nodes or the wireless transmitting power. These methods are not suitable for the sparse applications. We propose a Chain Mobile Model (CMM), aiming to ensure the routing quality as much as possible. In the chain model, the nodes are divided into task nodes (i.e., MIATs, that is master node, also be called as the head node) and relay nodes (i.e., MIARs, that is slave node). Task node calls for a variety of devices to complete the monitoring and control tasks, while relay nodes (i.e., MIAR) to complete the task of reply communications. In the moving process of nodes, i (i>0) mobile nodes are arranged in a chain formation, moving at the speed $\vec{V}(t)$, in a separation distance of L meter (s) between the mobile nodes. After moving for a distance (less than mobile wireless transmission radius of nodes), node that rank last in the queue stops movement, acting as relaying node, while the rest of the mobile nodes remain in line and moved on. The above process is repeated until the task nodes reach the destination for the implementation of monitoring task. In CMM, the motion behavior of the node can be defined by (1) and (2), where ΔS_i is the distance between No. i node at stop and No. i-1 reply node; Δt_i is movement time between No. i node at stop and No. i-1 node at stop; R is wireless coverage radius, d_i is the initial distance between No. i node and No. i-1 node. f is function output ranged between 0 and 1, q_1 and q_2 are the forward and reverse link quality between nodes, in a range of 0 and 1. k_1 is the parameter of environmental barriers and k_2 for wireless interference parameter; á is the attenuation factor of the wireless environment and the greater the environmental decay, the greater the parameter:

$$\begin{aligned} &\Delta S_i = f((q_1 * q_2)^{\alpha}, k_1, k_2) * [\Delta t_i * |\vec{V}(t)| + d_i] \\ &\alpha > 1, \Delta t_i \in \left[0, R/|\vec{V}(t)|\right] \end{aligned} \quad (1)$$

$$\begin{aligned} &f((q_1 * q_2)^{\alpha}, k_1, k_2) = (1-K)(q_1 * q_2)^{\alpha}, \\ &K = (k_1 + k_2)/2, \quad K \in [0,1] \end{aligned} \quad (2)$$

Quality of forward and converse links (q_1 and q_2) would be considered only, in the case of existing obstacles or thinking over simple control.

In the chain model, in general, there are several nodes that will stop moving to act as relay nodes, in order to achieve communication between the CC and the head nodes in the widest possible range. By using CMM, fewer nodes are needed to form a longest routing chain of communication from CC to head node, so that the head node, in the implementation of monitoring and control tasks, is able to maintain the smooth flow of information with the CC to the possible extent.

TRANSMISSION WITH INVULNERABILITY

In practice, routing interruption may be caused by a number of reasons, such as the power depletion of the mobile agent, faults in the wireless communication module, or even being destroyed for some reason. When the ad hoc node communication has a failure leading to incomplete routing, the transfer of information between the nodes has been the problem the experts are trying to solve. The general solution is to wait passively for the routing recovery, which may lead to information unable to be interactive or to an intolerable delay. In this regard, we propose two options: One is to start the standby nodes to ensure the integrity of the routing when the nodes are detected to be disabled. The second is to start the information ferry program when the standby nodes are all consumed but still can't ensure the routing working smoothly and select the ferry agent to complete the information transmission.

Standby node program: According to the distance and complexity of the task, the control center figures out the number of relay agents and standby nodes. After the completion of chain formation, MIAT will transfer the collected data to the control center through the chain route. In this process, the invalidation of a MIAR will cause the routing disruption. As shown in Fig. 4,when the second MIAR in failure, the CC receives the comparing results of the current new routing Table 2 and route Table 1 prior to the failure, obtains the ID MIAR 2 and location of the L (2) of the relay mobile agent in fault. Then, it commands the standby node with maximum energy to the location of the disabled node, thus completing the chain route recovery. Standby nodes include MIAR and MIAT. When the MIARs are

Table 1: Pre-fault routing table

Number	Location	IP
CC	L(CC)	IP(CC)
MIAT	L(0)	IP(0)
MIAR1	L(1)	IP(1)
MIAR2	L(2)	IP(2)
MIAR3	L(3)	IP(3)
…	…	…

Table 2: Post-fault routing table

Number	Location	IP
CC	L(CC)	IP(CC)
RMIA1	L(1)	IP(0)

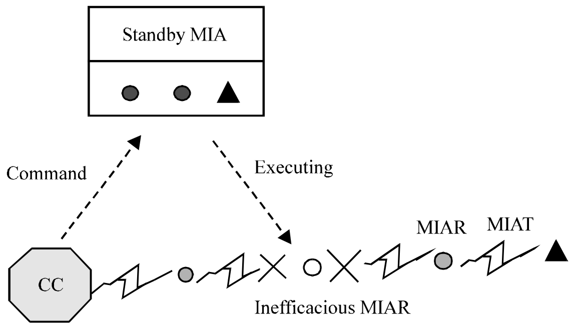

Fig. 4: Principles of standby node method

consumed, MIAT can act as a relay mobile agent. When failures occur in the implementation of MIAT, the standby MIAT will take over its work.

Information ferry program: In the case of the route failure, leading to MIAT being unable to have a contact with the CC, MIAT will start timing, with the time to be determined by the physical distance of the entire link and the complexities of the space obstacles. If the link does not return to normal in the set time, MIAT will startup information ferry program. When the link breaks down, the CC will also prepare for starting the information ferrying. But the condition arouses its ferrying information is more rigidly. We will discuss it at the third mode of ferry program.

The ferry program is implemented in three modes. First, when the MIAT detects a link down, around without any MIAR, it will return along the original trajectory in order to transfer the data to the CC. When link quality is detected to go above the setting values, the data collected will be transferred to the CC.

The second case is when the MIAT detects the routing interruption, but there are MIARs that are connected to it, ferry agent will be selected using the Q-learning algorithm in the reinforcement learning strategy (Watkins and Dayan, 1992; Li *et al*., 2010):

$$Q(s,a) = r(s,a) + \gamma \times \max_{b} Q(S_{next}, b)$$
$$\gamma = \frac{QNC \times RE}{H} \quad (3)$$

In Eq. 3, Q (s, a) represents the value of discounted cumulative return obtained in the implementation of action 'a' in state 's' and is the discount rate, γ. $0 \le \gamma \le 1$ is the factor of future returns being translated into the current value. The greater the value, the greater the current impact of the future returns; r (s, a) is immediate return obtained by taking an action and 'b' is the action that can be taken at the next state. In the selection process of ferrying agent, Quality of Networks Connection (QNC), Residual Energy (RE) and the number of hops (hops --- H) between MIARs and MIAT, all integrated into an immediate return value. When MIAT chooses information ferrying node, it can calculate and choose the MIAR whom has the biggest Q value. Ferry agent receives the data from task mobile agent and travels back along the original trajectory. When ferry agent detects a route to CC and the link quality of data is higher than a default minimum value for transmission of data, the stored data will be transferred to the CC to complete the information ferry mission.

There are three prerequisites for the third case :(1) When the CC detects routing disruption, (2) the standby agent not available for replacement at fault, (3) in the case of exceeding the set time value of ferry transport. When all of these happen, the CC still will use Q-learning algorithm in reinforcement learning strategy, except at this time, γ shows a slight change. Here, L_1 is connecting distance mobile agent from the relay to the CC before an interrupt; L is the distance from CC to MIAT before the link was broken; λ is the constant in [0.5, 1] and here, 0.5. The control center commands the agent with the largest Q value to implement the information ferrying task. Along the original movement line of MIAT, the agent will search the task mobile agent, following by storing the data of it. Meanwhile, the commands of CC will be transferred to the MIAT. The commands issued by the CC determine whether the MIAT is to return or to immediately perform other tasks:

$$\gamma = QNC \times E \times (L_1/L)^{\lambda} \quad (4)$$

WIRELESS SENSOR NETWORKS AND NETWORKING METHOD

Design of the WSNs nodes: Since the measurement requires the monitoring of environmental information including sound, brightness, temperature and humidity, LPC2114 is chosen as the controller, with real-time operating system μC/OS-II to build a software platform, Bluetooth as a wireless means of communication, while temperature and humidity sensors, photo resistors and microphone are combined to form the sensor data acquisition unit. Wireless sensor node is divided into four layers, of which the top layer is the Bluetooth communication module and the acquisition module of temperature and humidity, while the brightness and noise are collected in the second layer and the third layer is the system board LPC2114, with power supply in the next layer as shown in Fig. 5.

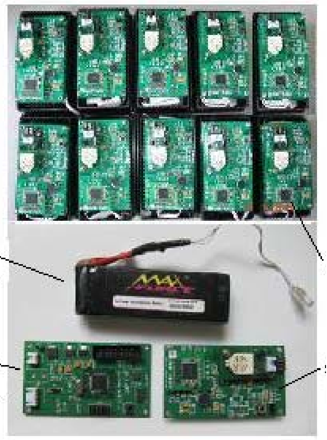

Fig. 5: Wireless sensor network nodes

Networking method by kindred tree: The project requires relatively less wireless sensor network coverage and the number of nodes, so there is no chance to highlight its advantages by using complex routing protocols and algorithms in this case and the complex protocols need more software and hardware. Their relations are difficult in practical applications. In view of the requirements for saving energy, hardware resources and simple implementation, a kindred tree network structure is designed in connection with the wireless sensor networking method that is based on a single path. This enables the WSNs nodes that only need a simple processing to be able to build up the network routing tables, while ensuring a stable and reliable network. Here, the single path refers that a node which has only one route to travel to any other node in the network. The method is designed to have less network links and node capacity, making the network very simple, reducing the energy consumption of nodes. Establishment of links between nodes will be followed by immediate update of routing information. Nodes send over their routing information to each other, while receiving the routing information issued by the other party. And then routing information can be processed to establish a route to other nodes. In the next step, their routing information is sent down to the next hop to inform the update of node and so on, until the routing update of all nodes is completed. After the completion of networking, each node stores the routing information of all nodes, thus ensuring a simple and reliable network.

In the course of realizing the algorithm, the key part is to avoid forming a ring, which may result in data packet transmission in the ring. Here are two methods that may be used to prevent the happening of such events: first, use random number delay when starting the search; Second, when a node encounters the same physical address in different route, the shortest route will be retained and the other routing node is notified with the destination node to repeat the nearest route, where you need to disconnect and reconnect it. At the same routing hops, physical addresses will be compared in size to determine the break point.

SIMULATION AND EXPERIMENT

The simulation involves seven mobile agents, in which one is employed as the control center, one as the MIAT and five as MIARs, including a standby agent, in a range of motion 500×500 m. An agent has a circular communication range of 120 m. Agent speed is set to 0.4, 0.8, 1, 1.5 and 2 m sec^{-1}, respectively. Under Ad hoc On-Demand Distance Vector Routing (AODV), use Network Simulator version 2(NS2) to compare the performance of the network between the RPGM and our methods in different speed. In this study, a contrast is performed on packet drop rate and average throughput in the communication process, as shown in Fig. 6 and 7.

Figure 6 shows that when the moving speed increased from 0.4 to 0.8 m sec^{-1}, the packet drop rate of RPGM will be twice larger as that by our method. When the moving speed increased from 0.8 to 1.0 m sec^{-1}, the packet drop rate of RPGM will be doubled, while only 50% risen would be gotten by our method. When the speed is greater than 1 m sec^{-1}, RPGM's packet drop rate will go up faster, but little change shown in our approach. As a whole, the packet drop rate of RPGM is twice or even larger as that by our method.

Figure 7 shows that when the moving speed increased from 0.4 to 0.8 m sec^{-1}, the throughput of RPGM will be triple as by our method. When the speed increased from 1 to 1.5 m sec^{-1}, the throughput will change slowly in both methods. When the speed increased from 1.5 to 2 m sec^{-1}, the throughput of RPGM will have a slight decrease, while it will decrease to a half by our method. As a whole, with the increase of moving speed, the throughput will decrease in both methods, but twice or even larger throughput will be gotten if using our method. According to the analysis above, our method significantly improves the throughput and reduces the packet drop rate.

In actual experiment, seven mobile agents are used to move in a range of 500×500 m. The seven mobile agents include one MIAT, five MIARs, plus one standby smart agent. The road to the monitoring site is mostly made of concrete pavement, in the presence of some obstacles, such as stones and artificial square and

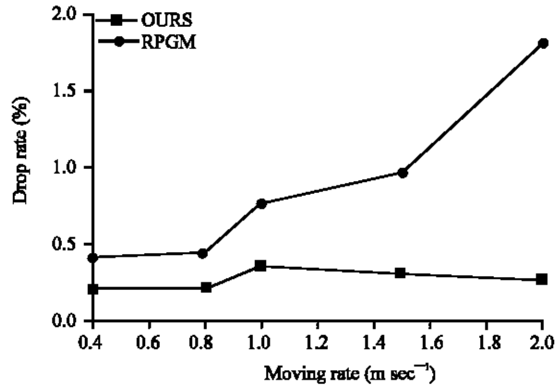

Fig. 6: Contrast of drop rate

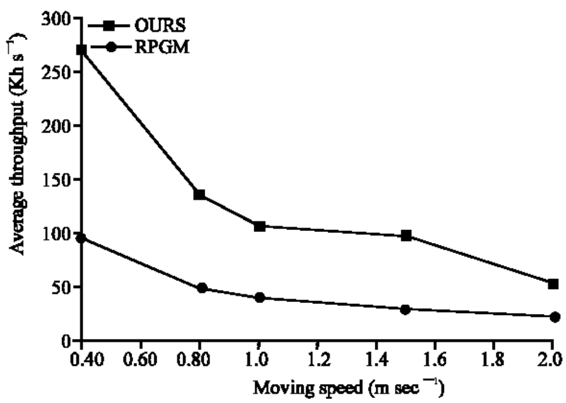

Fig. 7: Contrast of throughput

cylindrical settings. Fifty wireless sensor nodes are selected for coverage on part of the area. First, the CC commands the MIAT to particular coordinate to collect the environmental information and tests the network transmission of chain formation. Second, the failure is simulated by turning off the power supply of a MIAR, observing the effectiveness of the standby strategy. Third, turn off the more power supplies of MIARs, resulting in consistent information on ferry transport conditions, so that to observe result of ferry information. Fourth, test the reliability of wireless sensor networking separately. Experiments show that the CC is able to receive the environmental information and audio and video information from the measurement area in the first three experiments. Especially in the third experiment, the network shows strong intelligence and invulnerability. In the fourth experiment, when the sensor nodes are relatively sparse, the wireless sensor networks have a short time for the kindred tree networking and strong in self-healing ability. But in the presence of network nodes being more intensive, the networking of WSNs is time consuming and not stable.

DISCUSSION

In Epedemic protocol, the message is copied too many times, the nodes do not have intelligence and too much network and processor resources are wasted. In the controlling transmission mode, the node which is most likely to transmit is estimated by the way of using probability. So, the link formatted is suitable for predetermined transmission. Ferry nodes have the ability to communicate in interruption, but better constraints are needed when to choose it.

Compared with Epedemic, the communication nodes we proposed have good intelligence. They can also copy data with a purpose and reduce the resources' waste. Moreover, the Q-learning algorithm is used to choose ferry nodes in the program, to restrict them. Our work not only improves the single method above, but also considers various problems in application.

In wireless sensor networks, the method proposed is easy to implement, but with the increase of the network nodes, too many hardware resources are required, so the efficiency will be relatively low. In specific applications, the variety strategies have a relatively better ability to adapt and survive than a single model. Studies have shown that enhancing the intelligent mobile agent is very important, can effectively improve network reliability.

CONCLUSION AND FUTURE WORK

The sparse communication nodes are commonly found in practical applications, where the reliability of communication links is likely to face a severe test. At the same time, the application may encounter with various conditions causing the node unable to work. How to complete the information transmission is of great importance at that moment. This study describes a hybrid intelligent monitoring network based on ad hoc and WSNs and provides a chain formation model to improve the link quality, while two methods are proposed to improve the survivability of transmission performance. This monitoring method formed by a composite network shows an important value on special occasions and plays an active role in dangerous occasions. Future research is to improve the intelligence of mobile agent and research the methods for multi-task synergy among mobile intelligent agents.

ACKNOWLEDGMENT

This study was supported by the National Defense Advanced research Project (Grand No.3120060264)' should be changed to 'This study was supported by

Ministry of Industry and Information Technology of PRC (Grand No.3120060264)'.Because the Commission of Science, Technology and Industry for National Defense had been changed to the special department of Ministry of Industry and Information Technology of PRC, the latter is the sponsor.

REFERENCES

Akyildiz, I.F., W. Su, Y. Sankarasubramaniam and E. Cayirci, 2002. Wireless sensor networks: A survey. Comput. Networks, 38: 393-422.

Boppana, R.V. and X. Su, 2010. On the effectiveness of monitoring for intrusion detection in mobile Ad hoc networks. IEEE Trans. Mobile Comput., 10.1109/ TMC.2010.210

Caleffi, M., G. Ferraiuolo and L. Paura, 2007. Augmented tree-based routing protocol for scalable ah hoc networks. IEEE Internatonal Conference on Mobile Adhoc and Sensor Systems, Nov. 20, IEEE Press, pp: 1-6.

Chlamtac, I., M. Conti and J.N. Liu, 2003. Mobile ad hoc networking: Imperatives and chanllenges. Ad Hoc Network, 1: 13-64.

Cruller, D., D. Estrin and M. Srivatava, 2004. Overview of sensor networks. IEEE Comput., 37: 41-49.

Ghinita, G., M. Azarmi and E. Bertino, 2010. Privacy-aware location-aided routing in mobile Ad hoc networks. Proceedings of the 11th International Conference on Mobile Data Management, May 23-26, Kanas City, Missouri, USA., pp: 65-74.

Jindal, A. and K. Psounis, 2006. Performance analysis of epidemic routing under contention. Proceedings of the International Conference on Wireless Communications and Mobile Computing, July 3-6, Department of Electrical Engineering. University of Southern California, pp: 539-544.

Li, M., Y. Xu and Y. Cai, 2010. Q-learning based sensing task management algorithm for cognitive radio systems. J. Electronics Inform. Technol., 32: 623-628.

Matsuda, T. and T. Takine, 2008. (p,q)-Epidemic routing for sparsely populated mobile ad hoc networks. IEEE J. Selected Areas Commun., 26: 783-793.

Singh, G., A. Subramanian and Y.L. Guan, 2007. Location Aided Directed Routing (LADR) protocol for mobile Ad-hoc networks. Proceedings IEEE 18th International Symposium on Personal, Indoor and Mobile Radio Communications, Sept. 3-7, Athens, pp: 1-5.

Tariq, M.M.B., M. Ammar and E. Zegura, 2006. Message ferry route design for sparse ad hoc networks with mobile nodes. Proceedings of the International Symposium on Mobile Ad Hoc Networking and Computing, May 22-25, Florence, Italy, pp: 37-48.

Watkins, C.J.H.W. and P. Dayan, 1992. Tecknical note: Q-learning. Mach. Learn., 8: 279-292.

Wu, K., Q. Yu and Y. Tian, 2010. A novel location-aided ad hoc on-demand vector routing protocol. Acta Electronoca Sinica, 38: 983-988.

Yan, W., W. Guo and J. Liu, 2008. An improved algorithm for olsr protocol based on signal strength. Telecommun. Eng., 48: 40-45.

Zhang, T., Z. Li and M. Liu, 2006. Routing in partially connected wireless network. J. Syst. Simulat., 18: 2972-2975.

Zhao, W., M. Ammar and E. Zegura, 2004. A message ferrying approach for data delivery in sparse mobile ad hoc networks. Proceedings of 5th ACM International Symposium on Mobile Ad Hoc Networking and Computing, Tokyo, Japan, May 24-26, ACM Press, pp: 187-198.