# A Routing Scheme for Supporting Network Mobility of Sensor Network Based on 6LoWPAN*

Jin Ho Kim[1], Choong Seon Hong[1], and Koji Okamura[2]

[1] Department of Computer Engineering, Kyung Hee University
{jinhowin,cshong}@khu.ac.kr
[2] Computing and Communications Center, Kyushu University
oka@ec.kyushu-u.ac.jp

**Abstract.** Network Mobility (NEMO) and IPv6 over Low power Wireless PAN (6LoWPAN) protocols are the two significant important technologies in the current networking research areas and seem to be vital for the future ubiquitous environment. It can maximize the ripple effect of ubiquitous revolution due to the close correlation between NEMO and 6LoWPAN. In this paper, we propose an interoperable architecture between NEMO and 6LoWPAN. To accomplish our goal we have enhanced the routing protocol: An extended routing scheme for mobile routers to support mobility in 6LoWPAN sensor nodes. Enhanced routing scheme performs default gateway discovery and mobile network prefix discovery operations for packet forwarding, path optimization and backup route maintenance. Simulation shows that our mechanism is capable of minimizing the routing overheads, and end-to-end packet delay.

## 1 Introduction

WSN (Wireless Sensor Network) is one of the fastest growing segments in the ubiquitous networking today. Currently some sensor network protocols have non-IP network layer protocol such as ZigBee[1], where TCP/IP protocol is not used. However, future WSNs consisting of thousands of nodes and these networks may be connected to others via the Internet. Hence, efficient addressing mechanism will be needed to communicate with the individual nodes in the network. IPv6 can be the best solution for that. Also promising and suitable application is needed which can make effective use of IPv6 address. Accordingly, IETF (Internet Engineering Task Force) 6LoWPAN (IPv6 over Low power Wireless PAN) Working Group[2] is organized to define the transport of IPv6 over IEEE 802.15.4[3] low-power wireless personal area networks. So, external hosts in IPv6 Internet can directly communicate with sensor nodes in 6LoWPAN, and vice versa, as each sensor node will be assigned a global IPv6 address. With the help of IPv6 addressing, it is relatively easy to add mobility support in WSN. When node moves to other link from home link, there are many messages overhead e.g. BU (Binding Update) [4], BA (Binding Acknowledgement)

* "This work was supported by the Korea Research Foundation Grant funded by the Korean Government (MOEHRD)" (KRF-2006-521-D00394).

S. Ata and C.S. Hong (Eds.): APNOMS 2007, LNCS 4773, pp. 155–164, 2007.

messages[4]. As Mobile IPv6 protocol[4] is designed for host mobility support, nodes changing home link must exchange those messages for successful operation. As a consequence, Mobile IPv6 protocol is very inefficient for energy and computing constrained sensor nodes. We assume sensor network is homogeneous and mobility is as a unit of network (same like NEMO[5]). If NEMO is applied in sensor network, even though each node is not equipped with mobility protocol, it can maintain connectivity with the Internet through MR (Mobile Router) as a network unit. Also, sensor nodes should have IPv6 stack as NEMO protocol[5] is based on IPv6. Hence, the network mobility of the sensor nodes is supported by interoperable architecture technology between 6LoWPAN and NEMO.

In this paper, we propose an interoperable architecture between NEMO and 6LoWPAN. To the best of our knowledge this is the first work on interoperable architecture between NEMO and 6LoWPAN. To accomplish the inter operability, we have enhanced the routing protocol: An extended routing scheme for mobile routers to support mobility in 6LoWPAN sensor nodes. Enhanced routing performs default gateway discovery and mobile network prefix discovery operations for packet forwarding, path optimization and backup route maintenance.

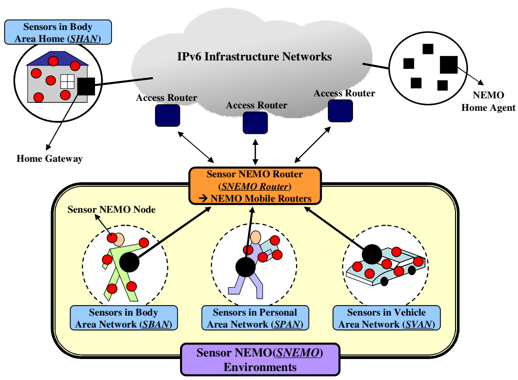



**Fig. 1.** Sensor NEMO (SNEMO) Environment

Figure 1 shows a Sensor Network Mobility (SNEMO) environment, which is integrated with NEMO and sensor network (6LoWPAN) protocols. This is the reference model used in this paper. SNEMO environment has three components: MR (Mobile Router), sensors, and AR (Access Router). MR use NEMO protocol that provides network mobility to each sensor node. An optimized route Internet connection is supported by mesh routing between the mobile routers. Sensors are equipped with IPv6 to be operable with NEMO environments. AR acts as the IPv6 default Internet gateway to the mobile routers.

Our paper is organized as follows. Section 2 introduces some related works such as NEMO and 6LoWPAN protocol. In section 3, we briefly described the operations of a suitable routing scheme for 6LoWPAN. Then we show the results and their performance evaluations in section 4. Finally, we conclude in section 5.

## 2 Related Works

***Network Mobility.*** When a packet is sent to a fixed node in mobile network by using the Mobile IPv6 protocol, first it is transmitted to home network corresponding to the mobile network. But, home network does not know the information about the nodes moving with-in mobile network. The transmission is failed by routing loop occurring between the default router and the HA (Home Agent). To avoid the problem of the routing loop, we adopt explicit mode of NEMO protocol[5]. Prefix information of mobile network nodes are supplied to the mobile router, which is in charge of the mobile network. The mobile router sends a Binding Update message with mobile network prefix. Then, home agent for mobile router will be able to know the location of nodes moving with mobile router. Mobile network nodes that belong to the mobile router receiving the packets are directed to the current address for mobile router using tunneling. Thus, packets will reach to the final destination via mobile router. However, NEMO basic protocol does not solve the route optimization problem. The reason is that packets between CN and MNN would be forwarded through a bi-directional tunnel which is established between MR and its own HA. In case of a nested NEMO, packets would travel through the all of the HAs. Therefore, packet routing problem is more serious in nested NEMO. There are some solutions to solve route optimization problem such as ORC[6], RBU[7], ONEMO[8]. And MANEMO (Mobile Ad Hoc NEMO: integration of MANET and NEMO protocol)[9] solves the problem of route optimization in the nested case.

***6LoWPAN.*** There are many problems in using existing IP-based infrastructure by adapting IPv6 mechanism to LoWPAN[10]. Specially, MTU for IPv6 is 1280 bytes, but PDU for 6LoWPAN is only 81 bytes. Accordingly, there is a need for Adaptation layer between IP layer and LoWPAN MAC layer[11]. Adaptation layer provides the fragmentation and reassembly process. 6LoWPAN should also support IPv6 automatic address configuration. In order to support multi-hop mesh network for 6LoWPAN, a routing protocol is required. AODV (Ad-hoc On-demand Distance Vector)[12] for MANET (Mobile Ad-hoc Networks) can be alternative plan for multi-hop routing protocol for 6LoWPAN. However, in order to adapt AODV for the 6LoWPAN, it should be adaptable for 6LoWPAN without fragmentation. LOAD (6LoWPAN Ad Hoc On-Demand Distance Vector Routing)[13] is the routing protocol which transmits the packet from 6LoWPAN to multi-hop node. LOAD, which is a simplified version of AODV, uses lightweight control and routing tables to adapt to 6LoWPAN using limited traffic and memory. Its basic operation is similar to AODV. First, it searches the path by broadcasting RREQ message and then decides the path after receiving RREP message. In order to adapt LoWPAN to IPv6 and IP-based networks, a gateway is needed. It is an important process for the gateway to convert the packet for LoWPAN into the IP-based packet.

## 3 Routing Scheme for Supporting Network Mobility of 6LoWPAN

In this section, we explain detailed operation of a suitable routing scheme for supporting network mobility of the sensor network based on 6LoWPAN.

### 3.1 Internet Gateway Discovery

If mobile network including 6LoWPAN sensor nodes cooperates with IPv6 Internet, 6LoWPAN default Internet gateway should exist between the 6LoWPAN network and the IPv6 Internet network. A mobile network can be consisting of hosts and mobile router. Mobile network communicates with the Internet gateway directly or using intermediate mobile routers. Each Internet gateway consists of one or more different subnets. Internet gateway has IEEE 802.15.4 interface to communicate with mobile network nodes and wired interface to communicate with IPv6 network. It performs packet routing function between mobile network and IPv6 Internet. Different mobile routers organize mesh network by IEEE 802.15.4 egress interface. When new mobile router moves to other link from home network, it sends a Binding Update message to home agent. However, unfortunately it is not sure of the route to the home agent, as mobile router doesn't know where the Internet gateway is located in the network. Thus, mobile router executes Internet gateway discovery in the current network. Figure 2 shows an Internet Gateway Request (IGREQ) and an Internet Gateway Reply (IGREP) messages format to discover the Internet gateway in the network.

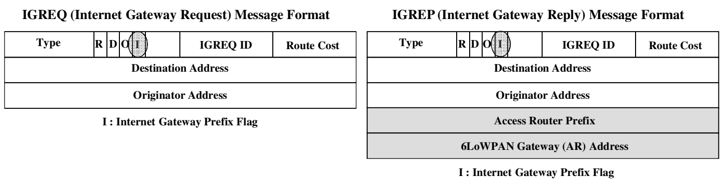



**Fig. 2.** Internet Gateway Request (IGREQ) and Internet Gateway Reply (IGREP) messages format

The mobile router sets the I-flag that means an Internet gateway prefix flag in the IGREQ message, and broadcasts it in the network (shown in figure 3(a)). At the same time neighbor mobile routers receiving the IGREQ message (as shown in figure 3(b)), will forward the message to the destination access router. Routing overhead of this method is reduced as compared to the other ad-hoc routing protocols such as AODV or LOAD, because IGREQ message is unicast rather than broadcast. As shown in figure 3(c), if the Internet gateway receives the IGREQ message, and sends an IGREP message to new mobile router immediately. The IGREP message includes a prefix and IPv6 global address (6LoWPAN Gateway address) of the access router. Mobile router constructs CoA (Care-of Address) in terms of the prefix information in the IGREP message. Each mobile router may receive multiple IGREP messages, which indicate the mobile router can access more than one Internet gateway. In the case of multiple Internet gateways, the mobile router establishes default Internet gateway according to the 'route cost' field of the received IGREP messages. Figure 3(c) displays the IGREP message route. New mobile router can receive prefixes and addresses information of AR1 as well as AR2, and the mobile router selects the best routing paths to the default Internet gateway. In this case the AR2 has been selected the Internet gateway.

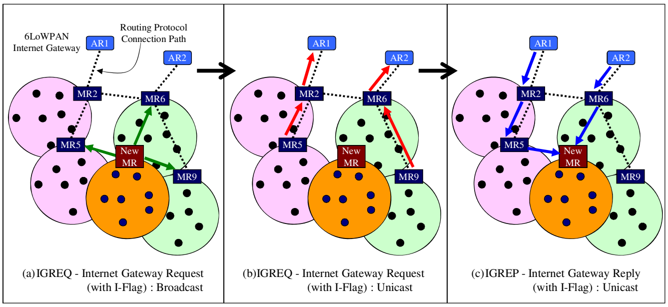



**Fig. 3.** Internet Gateway Discovery operation

### 3.2 Home Registration

If the mobile router detects its movement in the foreign network, the mobile router selects the path of the default Internet gateway, and has to perform home registration process in order to register the movement information. The mobile router sends Binding Update message to home agent as shown in figure 4. The Binding Update message includes mobile network prefix option, and home address option. In the figure 4, IPv6 header of source address is a CoA which is constructed by the access router prefix in the IGREQ message, and destination address is default Internet gateway. If the mobile router sends the Binding Update message, AR2 updates the mapping table entry (such as home address of mobile router, interface ID of CoA, and mobile network prefix). And then access router forwards it to home agent. If the Binding Update message is successfully transmitted to home agent, it will reply with Binding Acknowledgement message. The format is shown in the figure 4. The source address is home agent address and destination address is access router address. Then home agent sends the Binding Acknowledgement message to the mobile router. If this operation is successful, home registration process will be succeeded. Now sensor nodes can communicate with IPv6 Internet hosts successfully.

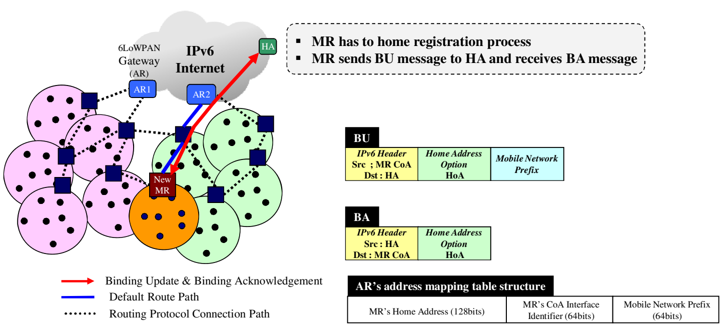



**Fig. 4.** Home Registration operation

### 3.3 Packet Routing

After home registration operation, sensor nodes in the mobile network want to communicate with Internet hosts. However, it is difficult to understand whether the node wants to communicate with the node inside the network or outside the network. If mobile router has route entry about the destination nodes, the node can transmit the packet through mobile router. On the other hand, mobile router should decide whether destination node is located in the mobile network node or not. To accomplish this, the mobile router should know mobile network prefix discovery and distinguish the location of the destination node.

***Communication between 6LoWPAN nodes in another mobile network.*** Figure 5 shows the communication between 6LoWPAN nodes in the same mobile network.

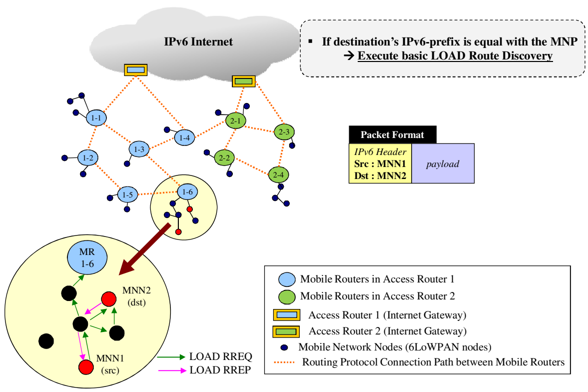



**Fig. 5.** The scenario of communication between 6LoWPAN nodes in same mobile network and its packet format

After considering the prefix of the destination node, source node will be able to know whether destination node is internal or external node in the current mobile network. If destination's IPv6 prefix matches the mobile network prefix, source node executes the basic LOAD route discovery. If route entry exists in the routing table, packet is delivered by routing connection path information. Otherwise source node sends RREQ messages to destination node and receives RREP message to establish the route path. And then source node can send the packet to the destination node.

***Communication between 6LoWPAN nodes in another mobile network.*** If location of the destination node is in another mobile network, i.e. not in the same network, the mobile router of current mobile network executes mobile network prefix discovery between neighbor mobile routers. The prefix information of destination node is broadcasted to neighbor mobile router by setting P-flag of MNPREQ (Mobile Network Prefix Request) message. Upon receiving the message, mobile router sent MNPREP (Mobile Network Prefix Reply) message by setting P-flag. This indicates there is a mobile router corresponding to mobile network prefix of the destination node. If the mobile router successfully complete the mobile network prefix discovery, it is possible to communicate via an optimized route to the neighbor mobile router. If P-flag has been set 0 in the MNPREP message, the mobile router decides that destination node is an Internet host, so transmits the packet to the Internet gateway. Figure 6 shows the format of MNPREQ and MNPREP messages for mobile network prefix discovery.

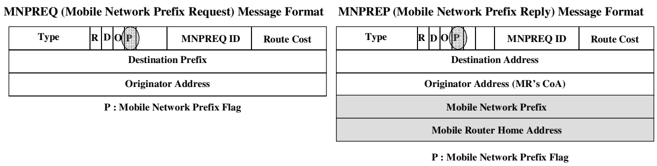



**Fig. 6.** Mobile Network Prefix Request (MNPREQ) and Mobile Network Prefix Reply (MNPREP) messages format

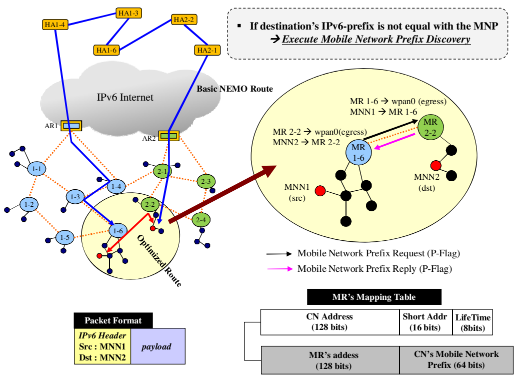



**Fig. 7.** The scenario of communication between 6LoWPAN nodes in another mobile network, its packet format, and mobile router's address mapping table

Figure 7 shows the communication between 6LoWPAN nodes in another mobile network. If destination's IPv6 prefix is not same as the mobile network prefix, the mobile router executes mobile network prefix discovery. As shown the figure 7, MR1-6 can transmit the packet to the destination node such as MNN2 after route path configuration. If the mobile network prefix discovery mechanism doesn't exist such as basic NEMO protocol or basic LOAD routing protocol, packet route leads to an inefficient result like detour route. In the case of the communication with another mobile network node, packet format and external mapping table of the mobile router appear in figure 7. And the mapping table stores mobile router's address and correspondent mobile network prefix's address.

***Communication between mobile network node and Internet host.*** As mentioned above if destination's IPv6 prefix does not match the prefix of current mobile network, mobile router performs the mobile network prefix discovery. In particular, the mobile router receives MNPREP message without P-flag from default access router, the packets should be forwarded to the default Internet gateway. As the destination

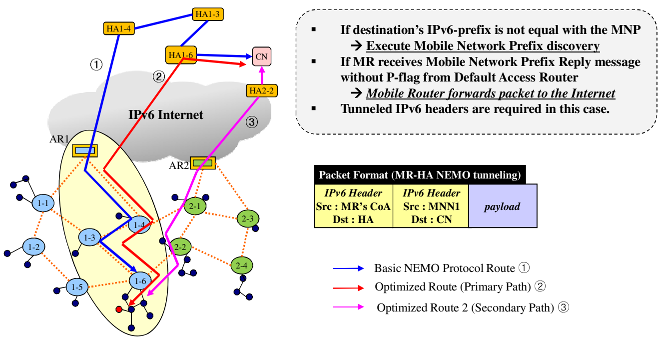


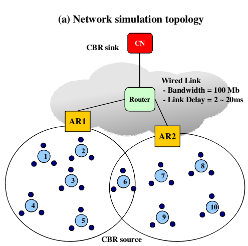

**Fig. 8.** The scenario of communication between mobile network node and Internet hosts, its packet format

node will be located in IPv6 Internet. The default Internet gateway makes a record in external address mapping table. Figure 8 shows the route between correspondent node in IPv6 Internet and mobile network node.

When operating NEMO basic protocol, the packet is sent to the destination by passing all home agents through the circuit path as shown in path (1) figure 8. But the packet is sent to the destination node by reducing the path via the only home agent of related mobile router like path (2). When it's not possible to connect with current Internet gateway, the mobile router also reduces packet loss rate by assuring the path to forward the packet to other Internet gateway like the path (3). Packet format for the communication between mobile network and Internet hosts is shown in figure 8. In addition, tunneled IPv6 headers are also required, because all of the packets are transmitted through the mobile router-home agent NEMO Tunnel.

## 4 Performance Evaluation

In order to measure performance of proposed routing mechanism, we configured the network topology as shown in figure 9(a). We measured routing packet overhead and end-to-end packet delay followed by the number of mobile router by using NS-2 (Network Simulator 2)[14]. We configured 100Mbps wired link among routers. AR network takes shape of mesh network by adapting AODV or LOAD routing protocol. Each mobile router includes three mobile network nodes. The parameters for simulation are stated in figure 9(b).




(b) Parameter for Simulation

| Parameter | Values |
|---|---|
| Area size | 500m * 500m |
| Number of Nodes | 10,20,30,40,50 |
| Send packets | 10 packets/sec |
| Data size | 50 bytes |
| Transmission range | 10m |
| Total time of simulation | 120sec |
| Traffic type | CBR |
| Number of Source | 5,10,15,20,25 |

**Fig. 9.** Simulation environment

Figure 10(a) shows the measured routing overhead for varying numbers of network nodes. We compare our protocol with AODV, LOAD routing protocol without mobility scenario, NEMO with AODV and NEMO with LOAD routing protocol. It is found that our proposed packet routing method has least routing overhead. Comparing to our proposed protocol, adaptation of original AODV protocol results in the higher routing overhead. Overhead incurred by LOAD routing protocol is lower than AODV, because HELLO message is not used. And AODV with NEMO and LOAD with NEMO have lower overhead than original AODV and original LOAD routing protocol, because in NEMO protocol routing path is searched only by mobile router. In our protocol, packet is delivered with lowest routing overhead, because proposed method is improved suitably for NEMO environment with operating process searching the path by selecting lower overhead than LOAD routing protocol.

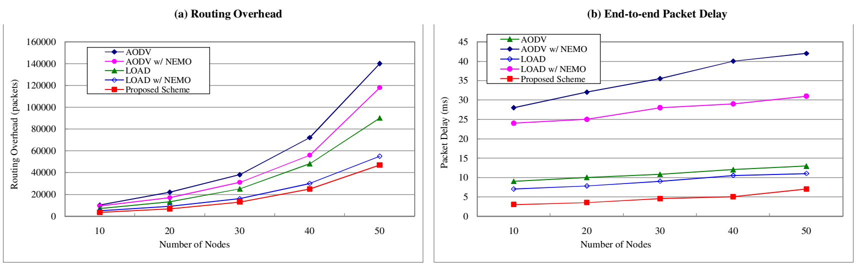



**Fig. 10.** Results of the routing overhead and end-to-end packet delay

The figure 10(b) shows the end-to-end packet delay experienced by CBR (Constant Bit Rate) traffic rate 10 packets per second, where each packet size of 50 bytes. Packet delay is much more in AODV with NEMO and LOAD with NEMO routing protocols than their original versions, the reason is packets are transmitted to the destination node via the home agent of each mobile router by NEMO basic protocol. In other words, delay time is increased because the routing path on Internet is extended. Packet delay is much lower in our proposed method as it transmits the packets only via the home agent of mobile router of source node. The above experimental results prove that proposed routing mechanism works efficiently than other proposed schemes in sensor network environment.

## 5 Conclusion

In this paper, we proposed the architecture for 6LoWPAN network mobility that also supporting communication between IPv6 node and sensor node. 6LoWPAN network is included in mobile router, although there's no mobility function for each sensor node. A sensor node works as a mobile network unit through mobile router with modified and defined LOAD routing protocol. Also, we have designed the mobile router architecture including the module of each layer. Mobile router detects its own default Internet gateway through the IGREQ (Internet Gateway Request) and the IGREP (Internet Gateway Reply) message, and after finishing this operation, it can communicate with Internet through IPv6 network and transmit Binding Update message to its own home agent. Therefore, mobile router can let home agent know its own current location. For optimized packet routing, through the MNPREQ (Mobile Network Prefix Request) and the MNPREP (Mobile Network Prefix Reply) message, it can exchange the prefix information between each other among neighbor mobile routers and can route the packet through optimized path between nodes. From simulation results we can conclude that the routing packet overhead and end-to-end packet delay are lower than other mechanisms.

## References

1. ZigBee Alliance, http://www.zigbee.org/en
2. IPv6 over Low power WPAN (6LoWPAN) Homepage http://www.ietf.org/html.charters/6lowpan-charter.html
3. IEEE computer Society, IEEE Std. 802.15.4-2003 (October 2003)
4. Johnson, D., Perkins, C., et al.: Mobility Support in IPv6. IETF RFC 3775 (June 2004)
5. Devarapalli, V., Wakikawa, R., Petrescu, A., Thubert, P.: Network Mobility (NEMO) Basic Support Protocol, IETF RFC 3963 (January 2005)
6. Wakikawa, R., et al.: ORC:Optimized Route Cache Management Protocol for Network MObility. In: The 10th International Conference on Telecommunications (February 2003)
7. Cho, H., et al.: RBU: Recursive Binding Update for Route Optimization in Nested Mobile Networks. In: IEEE 58th Semiannual Vehicular Technology Conference (October 2003)
8. Watari, M., et al.: Optimal Path Establishment for Nested Mobile Networks. In: IEEE 62nd Semiannual Vehicular Technology Conference (September 2005)
9. Wakikawa, R., et al.: MANEMO Topology and Addressing Architecture. draft-wakikawa-manemoarch-00.txt, IETF (June 2007)
10. Kushalnagar, N., Montenegro, G.: 6LoWPAN: Overview, Assumptions, Problem Statement and Goals. draft-ietf-6lowpan-problem-06, IETF (November 2006)
11. Montenegro, G., Kushalnagar, N.: Transmission of IPv6 Packets over IEEE 802.15.4 Networks. draft-ietf-6lowpan-format-08, IETF (November 2006)
12. Perkins, C.E., Belding-Royer, E.M., Das, S.D.R.: Ad Hoc On-Demand Distance Vector (AODV) Routing. IETF RFC 3561 (July 2003)
13. Kim, K., Daniel Park, S., Montenegro, G., Yoo, S., Kushalnagar, N.: 6LoWPAN Ad Hoc On-Demand Distance Vector Routing (LOAD). draft-daniel-6LoWPAN-load-adhoc-routing-02, IETF (March 2006)
14. Network Simulator (ns) version 2, http://www.isi.edu/nsmam/ns