

An Out-band Control Mechanism for Ad hoc Networks Routings

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Abstract— Energy conserving performance is an important criterion in routing protocol design in Ad hoc networks. In this paper, we propose a radio on-off control mechanism which requires an additional radio on each node to transmit control packets using a control channel for conserving energy. This mechanism allows idle nodes to turn off their data communication radios based routing information. The proposed method prevents nodes from wasting energy on idling and overhearing unintended data traffic. We apply the proposed mechanism to AODV routing protocol and compare it with original AODV and EA-AODV—a single channel energy conserving extension to AODV. Simulation results show that the proposed mechanism outperforms AODV and EA-AODV in conserving energy in static ad hoc networks.

Keywords— Radio on-off control, Ad hoc networks, Energy conserving, Control channel

1. Introduction

Ad hoc networks are distributed systems that consist of wireless nodes that are capable of communicating with others in their wireless transmission range without pre-existing infrastructures. Accompanied with convenience brought by flexibility and scalability, energy supports for nodes in ad hoc networks are usually limited due to their infrastructure-less nature. The energy depletion of nodes can easily lead to communication failures and network partitioning. Therefore, saving energy from being wasted becomes a vital issue in ad hoc networks.

Recent trends of reducing hardware cost and technique development have made it feasible to reduce the energy consumption by switching the radio into off or sleep state and to equip a network interface card with multiple radios. This also makes it possible to utilize multiple channels. In [2], S. Singh and his coworker proposed a power-aware multiple access protocol (PAMAS) for saving energy using a separate control channel, in which a node turns off its radio interface for a specific duration when it knows that it is not able to send or receive packets during that time due to the possibility of multiple access interference. Multi-channel has also been used in [3] and [4] separately to increase throughput and network capacity. However, the possibility of utilizing out-of-band channel for conserving energy in ad hoc networks has rarely been investigated so far.

In this paper, we propose radio on-off state control mechanism based on network layer decision to help conserve energy in ad hoc networks. The proposed mechanism requires an additional radio to transmit control packets using a control channel. The radio used for control channel is assumed to be always on, whereas that for data communication can be strategically turned on and off. So in following discuss, we use the term radio to represent radio for data communication. The radio used for changing control packets is assumed to consume very few energy in its idle state by using TDMA-based MAC protocol. We integrate the proposed mechanism with AODV (Ad hoc On-demand Distance Vector routing) [1]. The resulting protocol is referred to as AODV-ROC (AODV with Radio On-off Control). We introduce some background knowledge of energy consumption of network interfaces and out-of-band channel in section 2. In Section 3, we present the radio on-off state control mechanism together with routing process. Section 4 presents the simulation results generated by ns2 [6] and discussions. Finally, we conclude our work in Section 5.

2. Background

2.1. Energy consumption of wireless network interface

To enable the using of out-of-band channel, a multi-radio network interface has to be used. As has been studied in [5], an IEEE 802.11 based wireless network interface in idling state consumes as much power as when it receives data, because much of the idle energy consumption for a wireless NIC is from operating the radio at the baseband frequency, so that it can detect an arriving signal. In contrast, when a TDMA-style MAC is in use, the power consumption in idle state can decrease significantly. With a TDMA-style MAC, it is possible to put the radio in standby mode during only its own time-slots.

2.2. Out-of-band Channel

Note that all the processes mentioned above take place in a single channel. With only one channel in use, nodes cannot turn off their radios because they should always be ready to receive potential traffic from their neighbors, and therefore, waste lots of energy in overhearing unintended traffic.

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An out-of-band channel is typically used to separate control traffic from data traffic. In this paper, the newly added out-of-band channel is used for interchanging control packets of network layer. In practice, we can use a network interface card with two radios to utilize two channels.

3. Radio State Control Mechanism

In order to save the energy that is wasted in idling and overhearing state, we introduce a separate radio interface which consumes few energy in its idle state by using TDMA based MAC (as described in Section 2.1). The routing decision is made via the newly introduced channel. Therefore, the data communication radio interface, which is assumed to consume a significant amount of energy in its idle state according to IEEE 802.11 MAC standard, can be turned off when no connection is using it.

3.1. Networking Model

In single channel case, radios are required to be always on because they need to be ready for coming transmission. As has been studied in [5], a network interface card (NIC) consumes a significant amount of energy during its idle state in an IEEE 802.11 network. In addition, because physical layer control is not capable of distinguish unintended packets, a large number of packets are received by irrelevant nodes (e.g. nodes that are not involved in a specific transmission) as the wireless signal travel through the space. In order to prevent energy waste in above mentioned behaviors, we design a radio on-off control mechanism. This requires using an additional control channel.

In contrast to single channel case, the AODV-ROC uses a dual-channel model. Newly added protocol stack and channel are represented in gray boxes and are used for transmitting routing control messages. As shown in figure 1, the routing agent is separated into two functional modules. As with the name, Radio On-Off Control module can turn on and off the data communication radio. The decision is made based on the information produced by Routing Control Module, which does exactly the same things a conventional routing protocol does. We can use a TDMA-style MAC as the MAC layer protocol for the newly introduced radio to take advantages of its low energy cost in idle state [10]. So in the case that data communication radio is turned off and control radio is on, the idle power would be small.

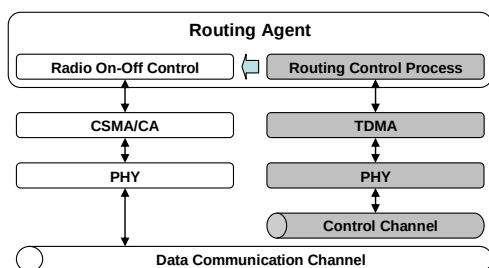


Figure 1. Radio On-Off Control based on Routing Information

In practice, the proposed networking model can be realized by using multi-radio network interface cards [9]. A brief introduction to the implementation of such networking model is given [11].

3.2. Radio State Transition in AODV-ROC

A key design issue in AODV-ROC is the on-off state control of data communication radio. The state diagram outlining the behavior of the radio state in AODV-ROC is depicted in figure 2. The ACTIVE_ROUTE_TIMEOUT is a constant used by routing table to purge stale routes. Routing table will set a path to invalid if it has not been used for this period of time. According to [1], this value is set in terms of real network environment, and we set it to 10 seconds in our simulation.

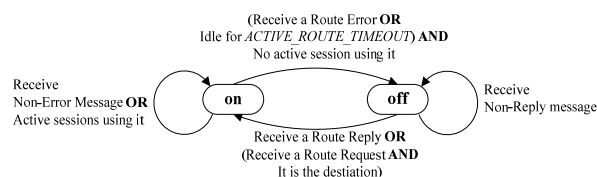


Figure 2. Data Radio on-off State diagram

During the route discovery process, a node switches its radio on when receives a route reply in control channel. And when it receives a route error message or does not receives any message using the current route within ACTIVE_ROUTE_TIMEOUT, the node checks if there is any other connection using it; if not, it will turn the radio off; or otherwise, keep the radio on since it still has to serve the other connection session. We use ACTIVE_ROUTE_TIMEOUT here because in the AODV if a node does not receive any message using the current path within this period of time, it will invalidate this path in its routing table. Therefore, turning off radios under this condition will not interrupt transmission, and in AODV-ROC case, its radio can be switched on again upon receiving the route reply.

3.3. Energy Consumption Discussion

The key factor that impacts the effectiveness of our proposed mechanism is the comparison between overhead introduced by our mechanism and the energy saved on the data communication radio. As long as the latter one is larger than the former, we consider our proposed mechanism is effective.

3.3.1. Energy Overhead

The overhead of on-off state switching introduced by our mechanism is actually very small because our mechanism requires the on-off switching at a very large time span. In other words, only a limited times (i.e. normally less than 50) of on-off switching is required, and the energy consumed by each on-off switch is pretty small (i.e. no greater than 0.001 Joule). Therefore, this overhead can be ignored when discussing the energy efficiency.

Another overhead is the energy used by the additional radio. The transmission and reception of control packets are rare event and usually take much lower energy than data communication. In addition, by using the TDMA based MAC, it takes much lower energy than its IEEE 802.11 counterparts.

3.3.2. Energy Saving

The energy saved by switching off the data communication channel is impressive. Because of the energy consumption behavior discussed in Section 2.1, it takes the number of neighbor nodes times the energy needed to receive one packet at one node to receive a packet in entire network. If our proposed mechanism is used, all irrelevant nodes are turned off, thus they will not expend energy in receiving unintended packets. In additional, because nodes will consume significant amount of energy in their idle state, it is wiser to turn them off in the case that potential routing control message can be received by control radio.

3.4. An Illustrative Example

We use a simple example to illustrate the working process and how it can control the on-off state of nodes based on network layer decision. Both the route discovery and maintenance processes are done in the control channel following the same procedures in AODV. To coordinate the work in two channels, a few changes need to be made in original AODV route discovery.

3.4.1. Route Discovery

As shown in figure 3a, 9 nodes are evenly distributed in a square area and their radios are turned off (represented by gray circles) at the initial state. Here we assume that the transmission range of each node can only cover its one-hop neighbors; for instance, in figure 3, node 1 can only communicate directly with nodes 2, 4, and 5.

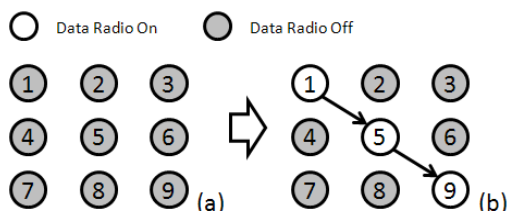


Figure 3. Radio state transition in route discovery

When node 1 wants to transmit data to node 9 and no route is available in its routing table, it broadcasts the route request in the control channel and all the intermediate nodes follows the operation specified in AODV. When node 9 receives the route request, it turns on its radio and sends back a route reply. Upon receiving a route reply, a node turns its radio on and waits for the coming data transmission. As shown in figure 3b, after the route reply reaches node 1, a forward path 1->5->9 with all the nodes along it turned on and data transmission can begin. In this case, all the nodes that are not on the path are turned off thus will not expend energy on idling and overhearing.

3.4.2. Route Maintenance

The route maintenance process is also done in the control channel. According to the specification of AODV routing protocol, route error packets will be sent once a path failure occurs. Differing from the single channel case, the proposed protocol requires a change that a node turns off its radio upon receiving a RRER packet if there is no other communication session (or has no available route in its routing table) using it. The downstream nodes of the failed link will turn their radio off after being idle for a period of time. The transition of radio state when a link failure occurs is given in figure 4. When the link between nodes 5 and 9 fails (figure 4a), a route error message is send back to erase routes in upstream nodes and turn their radios off (figure 4b). And node 9 will turn itself off (figure 4c) after waiting for ACTIVE_RO-UTE_TIMEOUT if no data are transmitted to it.

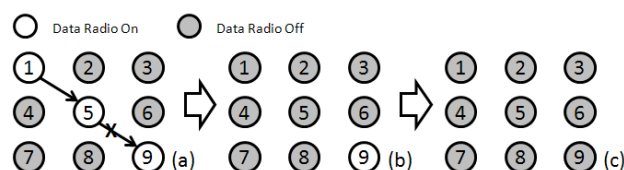


Figure 4. Radio state transition after a link failure

Benefited from the strategically turning off radios on idle nodes, some idle nodes in the network are well protected from expending energy on idling and overhearing.

4. Performance Study

In this section, we implement the proposed AODV-ROC in ns2 [6] and compare it with original AODV and EA-AODV [7]—a single channel energy conserving protocol—using simulation. EA-AODV turns a node into sleep if it has been idle for Tactive, and wakes a node up after sleeping for Tsleep. We assume each node used by AODV-ROC is equipped with a dual-radio network interface card and is capable of communicating with other node within its transmission range over two channels. Key parameters used in our simulation are given in TABLE I and TABLE II [5] [8]. IEEE 802.11b is used as the MAC layer for both radios. However, to better meet our assumption that it uses a TDMA-style MAC, we set the idling power consumption of radios used for control channel to 0.1 watt, as was done in [10]. And according to [7], Tactive and Tsleep are chosen as 100 ms and 115 ms respectively.

TABLE I. KEY ENERGY AND RADIO PARAMETERS

Transmission Range	250 meters
Transmitting Power	1.6 watts
Receiving Power	1.2 watts
Idling Power(Data)	1.15 watts
Idling Power(Control)	0.1 watt
Initial Energy	1060 Joules
Tactive for EA-AODV	100 ms
Tsleep for EA-AODV	115 ms

TABLE II. TRAFFIC PARAMETERS FOR EACH CONNECTION

Packet Size	512 bytes
Packet Type	UDP, cbr
Sending Rate	3 packets / second
Traffic pattern	Uniform

4.1. Line Topology

A line topology that consists of 5 nodes is shown in figure 5. Node 0 serves as the source node which generates traffic destined to node 4. We use line topology to investigate the scenario in which none of the nodes can be turned off during the transmission. This simulation runs for 700 seconds.

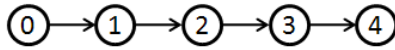


Figure 5. Line Topology

The consumed energy after running three protocols over the line topology is shown in figure 6.

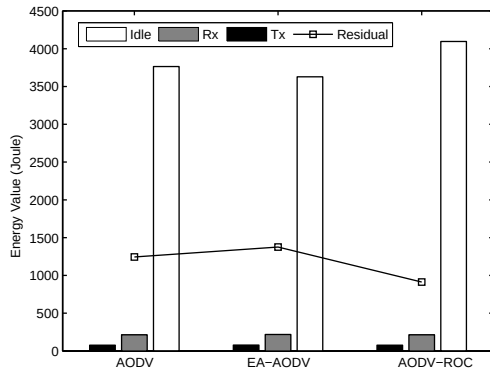


Figure 6. Energy consumption in line topology

As we expected, EA-AODV retains more energy, which is attributed to strategically turning off the radio interfaces. However, the improvement is not significant because nodes rarely have chances to turn off their radios. Similarly, in neither AODV nor AODV-ROC case, do nodes turn off their radios during the simulation. The proposed AODV-ROC performs worst in conserving energy in this scenario because the proposed mechanism never works—none of these nodes will turn off their radios during the data transmission—whereas the newly introduced radio interfaces consume extra energy.

4.2. Lattice Topology

As shown in figure 7, the lattice topology used in our experiment consists of 49 static nodes evenly distributed in a square area size of 1000m x 1000m. Here we use lattice topology to test the static regular scenario. 6 connections, as given in the figure, are used to generate traffics over the entire network.

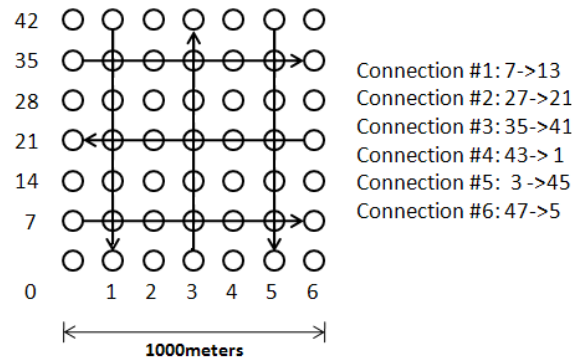


Figure 7. Static Lattice topology

Energy consumption of each behavior and the total residual energy after running simulation is plotted in figure 8.

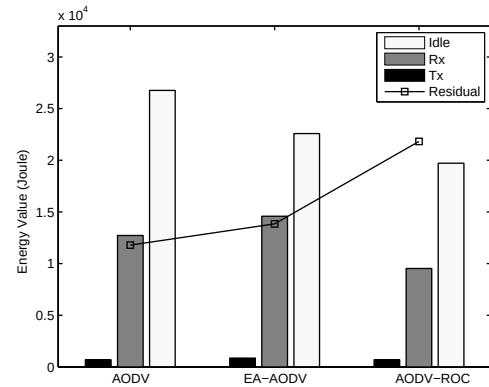


Figure 8. Energy consumption in lattice topology

Note that none of these nodes died in the tested scenario. As we can see from the figure, the proposed AODV-ROC consumes much fewer energy in idling and receiving state compared to the other two protocols and results in a higher residual energy value. This is because by using our proposed radio state control mechanism, many nodes can turn off their radios to prevent wasting energy on idling and overhearing.

5. Conclusions and Future Work

In this paper, we've proposed a radio state control mechanism and integrated it into AODV routing protocol to conserve energy in ad hoc networks. The resulting protocol named AODV-ROC differs from traditional routing protocol by strategically turning on and off the radios for data transmission while exchange control packets in a control channel. Properly turning off radios on nodes that are not involved in data communication can largely save energy by preventing idling and overhearing unintended traffic. Simulation results show that AODV-ROC outperforms AODV and EA-AODV in conserving energy in static ad hoc networks. Theoretical analysis of the efficiency of the proposed mechanism is to be studied in near future.

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