

Energy Efficiency of Load Balancing in MANET Routing Protocols

Sunsook Jung, Nisar Hundewale, Alex Zelikovsky *

Abstract

This paper considers energy constrained routing protocols and workload balancing techniques for improving MANET routing protocols and energy efficiency. We give new routing protocol that employs adaptive load balancing technique to the MANET routing protocols with node caching enhancement. Also, we show new application of energy efficiency metrics to MANET routing protocols for energy efficiency evaluation of the protocols with limited power supply.

Our contributions include: (i) New energy efficient AODV-based Node Caching routing protocol with Adaptive Workload Balancing (AODV-NC-WLB); (ii) New application of energy efficiency metrics to MANET routing protocols; and (iii) An implementation and simulation study in NS-2 of energy efficient AODV-NC-WLB sustaining considerable improvement in throughput, overhead, delivery ratio and delay over the standard AODV for high work load scenario.

Keywords: routing protocols, mobile ad hoc networks, Ad-hoc On-demand Distance Vector, routing load balancing, performance evaluation, network simulations, node caching, energy efficiency.

1. Introduction

Mobile ad hoc Network (MANET) is a special type of wireless network in which a collection of mobile network interfaces may form a temporary network without the aid of any established infrastructure or centralized administration. Ad hoc wireless network has applications in emergency search-and-rescue operations, decision making in the battlefield, data acquisition operations in hostile terrain, etc. It is featured by dynamic topology (infrastructureless), multi-hop communication, limited resources (bandwidth, CPU, battery, etc.) and limited security. These characteristics put special challenges in routing protocol design [1].

The one of the most important objectives of MANET routing protocol is to maximize energy efficiency, since

nodes in MANET depend on limited energy resources. Several routing protocols for MANET's have been suggested in late 90's: DSR, AODV, DSDV, TORA and others (see [2] for comprehensive review of these protocols). The classical MANET settings assume that neither node locations nor relative locations of other nodes are available. In this paper, we consider only protocols which do not rely on location knowledge – even if each node is supplied with GPS, the node mobility implies significant communication overhead caused by location updates.

The primary objectives of MANET routing protocols are to maximize network throughput, to maximize energy efficiency, maximize network lifetime, and to minimize delay. The network throughput is usually measured by packet delivery ratio while the most significant contribution to energy consumption is measured by routing overhead which is the number or size of routing control packets. The general consensus based on simulations (e.g., in the network simulator NS2 [3]) is that reactive protocols, i.e., those finding routes on fly by request with no work in advance, perform better than proactive routing protocols, which try to maintain the routs for *all* source-destination pairs (see [4]).

In hop-by-hop reactive routing protocols (e.g. used in Ad-hoc On-demand Distance Vector routing (AODV) [2]), every intermediate node decides where the routed packet should be forwarded next. Rout requests are generated at each hop by local broadcasting in case of path discovery. A simple flooding broadcast for route requests generates a considerable redundant packet overhead which is a major cause of inefficiency of MANET routing protocols. Jung et al [5] suggested constrained route request broadcast which is based on *node caching*. The nodes which are recently involved in data packet forwarding are cached and are used to forward route requests. Lee et. al. presented in [6] workload-based adaptive load balancing technique that is based on the idea that by dropping rout request packets (RREQ) according to the load status of each nodes, nodes can be excluded from route paths.

In this paper, we apply new energy efficiency metrics to MANET routing protocol. The goal of energy-aware routing protocol is to maximize the *network lifetime*. Also, we present new energy efficient routing protocol that uses adaptive load balancing technique to our previously presented node caching enhancement to the MANET routing protocol.

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Our contributions include:

- New energy efficient AODV-based Node Caching routing protocol with Adaptive Workload Balancing (AODV-NC-WLB);
- Novel application of energy efficiency metrics to MANET routing protocols;
- An implementation and simulation study in NS-2 of energy efficient AODV-NC-WLB sustaining considerable improvement in throughput, overhead, delivery ratio and delay over the standard AODV for high workload scenario.

The rest of the paper is organized as follows. The next section we discuss node caching enhancement and the adaptive workload balancing technique applied to reactive MANET routing protocols. Also, we present a new node cached MANET routing protocol with adaptive workload balancing. In the section 3 we exhibit the new approaches to evaluate energy efficiency in MANET routing protocol and details of application of energy efficiency metrics to the protocols. In section 4 explain how we generate our scenarios. In section 5 we give the results of our simulations in NS-2 comparing original AODV, AODV-NC, non-adaptive load balanced AODV-NC, and adaptive load balanced AODV-NC-WLB protocols.

2. Node Cached Routing Protocol With Adaptive Work Load Balancing

In this section, we first discuss node caching enhancement of AODV presented in [5]. Then we discuss the adaptive workload balancing technique applied to MANET routing protocol in [6]. Finally, we present a new node caching AODV with adaptive workload balancing which combine the protocols from [5] and [6].

Jung et al in [5] presented AODV-NC a novel approach to constrain route request broadcast which is based on *node caching*. The intuition is that the nodes involved in recent *data packet* forwarding have more reliable information about its neighbors and have better locations (e.g., on the intersection of several data routs) than other MANET nodes. The cached nodes are nodes recently involved in data packet forwarding, and use only them to forward route requests. As well as the previous approaches, node caching also employs the fact that the broadcast for route request is not really a broadcast - it does not need to reach all nodes but only a single required destination. Therefore, the protocol drops route requests forwarding from the nodes which are not cached at the expense of possible destination missing. Dropping route request forwarding from the other nodes considerably reduced routing overhead at the expense of possible destination missing. The authors overcame the known drawback of CDS – overuse of dominating (cached) nodes – by a new load-balancing technique. They performed extensive simulation study of AODV-NC in NS-2 showing (for stressed

MANET's) 10-fold reduction in overhead, significant improvement of the packet delivery ratio and the end-to-end delay. They also evaluated routing load distribution among MANET nodes. The simulation study in NS-2 of forwarding load balancing for AODV-NC sustained considerable improvement in overhead and delivery ratio.

The modified route request uses a fixed threshold parameter H . The first route request is sent with the small threshold H . When a node N receives the route request, it compares the current time T with the time $T(N)$ when the last data packet through N has been forwarded. If $T - H > T(N)$, then N does not belong to the current node cache and, therefore, N will not propagate the route request. Otherwise, if $T - H \leq T(N)$, then N is in the node cache and the route request is propagated as usual. Of course, the node cache cannot guarantee existence of paths between all source-destination pairs, therefore, if the route request with the small threshold H fails to find a route to destination, then a standard route request (which is not constrained by cache) is generated at the source.

On the other hand, AODV-NC has a limitation of using certain nodes (those form a CDS) unfairly to forward packets. The unfair forwarding load leads to reduction in networks lifetime and network partitioning. In order to prevent unfairness of node caching the authors relieve nodes which stay in cache for too long time. The authors suggested a load-balancing technique AODV-NC($H : n - t$) with the following two additional parameters – the threshold number of packets n forwarded during time t . If number of data packets forwarded by a node N during time period t is greater than n , then AODV-NC($H : n - t$) relieves the node N from forwarding cache-constrained route requests for the same time period t . During the break t , the node N still forwards data packets as well as standard unconstrained route requests. But the forwarding load for N decreases since new routes with high probability will avoid N .

However, the forwarding-load balancing algorithm is not self-adaptive because the proper parameter values are found through several experiments. It means that the value of parameters should be changed for every different situations.

Lee et. al. presented in [6] workload-based adaptive load balancing technique that is based on the idea that by dropping rout request packets (RREQ) according to the load status of each nodes, nodes can be excluded from route paths. This algorithm uses the length of the message queue in nodes and the outstanding workload which is defined as the combination of the queue length and residence time of packets in the queue. At the beginning of simulation, the minimum and maximum lengths of message queue and workload threshold are initialized. When a node receives RREQ packets, it checks the length of queue and calculates the average of two thresholds values. And then, a node calculates outstanding workload. If queue length is greater than the average threshold value and outstanding workload is greater than workload threshold, it drops RREQ packets.

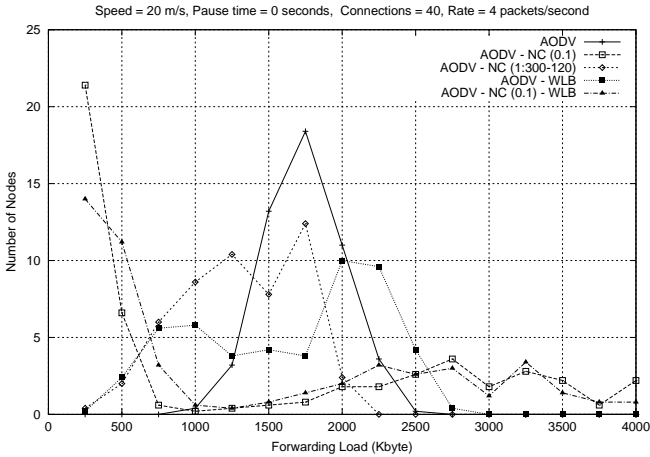


Figure 1. Distribution of the forwarding load among nodes for 40 connections.

Otherwise, the node forwards the RREQ packet to neighbors. In the meanwhile, a node calculates new threshold value of message queue length if outstanding workload is greater than workload threshold. According to the workload, threshold values are changed automatically.

We present AODV-NC-WLB that is a combination of the adaptive workload balancing technique presented in [6] with the node cached routing protocol in [5]. The forwarding-load balancing technique from [5] can not be combined with the adaptive workload balancing technique from [6]. The node caching technique is orthogonal to the adaptive workload balancing technique that allows to combine them without making major changes.

- We applied workload-based adaptive load balancing (WLB) [6] however; it does not solve the original unfair load balancing limitation of AODV-NC. On the other hand, it relieved nodes in high workload. (see Fig. 1)
- In regards to routing efficiency, for various speeds AODV-NC shows better performance than AODV-NC with non-adaptive load balancing as well as AODV-NC-WLB. In high connection scenarios, AODV-NC-WLB shows slight improvement in delivery ratio, relative overhead and end-to-end delay than the rest of the protocols. (see Fig. 6 and Fig. 7)
- AODV-NC-WLB improves energy efficiency. (see Fig. 3 and Fig. 4)

3. Energy Efficiency Metrics for Routing Protocols

In this section, first we discuss the energy efficiency metrics introduced in [7]. Then we present the details of applying energy efficiency metrics to evaluate energy efficiency

in MANET routing protocols. We also discuss how to measure the energy consumption in NS2.

Michail et. al. in [7] presented the performance metric for energy efficiency that measures average number of accepted calls per simulation time. The energy efficiency is measured by maximizing the time until the first node turns OFF (loses its power). That is when rest of the nodes start turning OFF.

We evaluate energy efficiency using following performance metrics:

- the total energy consumption in three different workloads.
- throughput as well as network lifetime with limited energy amount in nodes.
- the energy usage per packet, which is the ratio of the total energy consumption over the number of delivered data packets,
- the energy usage per hop, which is the ratio of the total energy consumed over the number of hops,

Network lifetime is defined as the time from beginning of simulation until first node in MANET runs out of energy.

We used energy model in NS2 to measure energy consumption of AODV, AODV-NC and AODV-NC with WLB. Even though the accuracy of energy model in NS2 has been pointed out in [8], we used this tool because we just focus on comparing efficiency of routing protocols in the same condition.

Energy model in NS2 has three states where energy is consumed: transmitting, receiving and idle state. Every node in NS2 starts with initial value which is the level of energy defined by user at the beginning of the simulation. It also has transmitting power(TXpower), receiving power(RXpower) and idle power parameters required by the node's physical layer. These values also can be defined by user. Initial energy level is decremented for transmission and reception of packets by TXpower and RXpower. When energy level in a node becomes zero, the node does not accept or send any packets.

We implemented the experiments under three different connections 20, 40 and 60. Speed 20 m/s was applied to all test cases and packet sending rate was 4 packet/sec.

In an experiment that assumes unlimited amount of energy, each of the nodes start with energy 1000J which is enough to maintain whole 1800 sec simulation. We set the TX power to 0.6W, RX power to 0.3W. At this time, we did not consider idle state because we were just interested in energy consuming with transmitting and receiving packets.

We also tested the situation of the energy in nodes that is not enough to remain alive until the end of the simulation. In this case, we set initial energy to 300J and set the power of idle state to 0.1W.

4. Simulations

The test cases were generated using built-in random generator in Network Simulator 2 (version NS-2.26) [3]. Our protocol evaluations are based on the simulation of 50 wireless nodes forming an ad hoc network, moving about over a 1000m×300m rectangle. The simulation time were 900 sec to evaluate general performances and 1800 sec to measure energy consumption. We recorded every results each 100 sec to oversee changes of results. The physical radio characteristics approximate the Lucent WaveLan direct sequence spread spectrum radio. In our experiment, we have set the communication range of mobile node to 250m. At media access control (MAC) layer the 802.11 MAC protocol has been used.

Parameters of our simulation model have been chosen close to one described in [4]. Nodes in simulation move according to a "random waypoint" model [9]. We generated all the movement scenarios using, *setdest* program in NS2. We have chosen traffic sources to be constant bit rate (CBR) sources. The sending rate varies from 1 to 4 packets per second, the node speed varies from 1 to 20 m/s, the number of connections varies from 10 to 60. Data packet size is 512 bytes and control packet size is 48 bytes. All traffic scenarios are generated using *cbrgen.tcl* in NS-2.

All results are the average of five different scenarios that have different seed numbers – 1500, 2000, 2500, 3000, and 3500. Jung et al [5], in their experiments with different threshold values of $H = 0.01, 0.05, 1, 0.1, 1.5$, and 10 for AODV-NC(H) found that 0.1 demonstrates the best performance. Therefore, we used threshold value of $H = 0.1$ for AODV-NC(H) protocol for this experiment. For AODV-NC($H : n - t$), we used threshold value of $H = 1$ and the number of forwarded packet threshold $n = 300$ during time $t = 120$ sec. In AODV-WLB, we initialized five parameters with the exactly same values as in [6].

Routing Efficiency Metrics. We compare ad hoc routing protocols reporting the following parameters:

- the relative routing overhead, which is the ratio of the number of control packets over the number of delivered data packets,
- the delivery ratio, which is the number of packets delivered over the total number of packets sent, and
- end-to-end delay, which is average of delays between each pair of a data communication session.
- the average number of hops and optimal hops,
- the normalized hops, which is the ratio of the average hops over the optimal hops and
- the plot of delivered packets versus average number of hops.

5. Results

In this section, we discuss energy efficiency and routing efficiency of MANET routing protocols using the performance metrics discussed in earlier sections.

Energy Efficiency. Fig. 3 shows energy usages of five routing protocols. AODV-NC(1 : 300 – 120) uses the least energy for a scenario with 20 connections while AODV-NC(0.1)-WLB uses the lowest energy usage for a scenario with 40 connections. This performance can be explained with relative overhead shown in Fig. 7. AODV-NC(1 : 300 – 120) and AODV-NC(0.1)-WLB show relatively lower routing overhead for connections 20 and 40 respectively. Since, these two protocols reduce routing request packets, it results in saving energy. AODV-NC(0.1)-WLB works better for high workload and requires less number of control packets therefore it is energy efficient in high workload scenario.

However, the differences among AODV and enhanced AODV protocols in regards to energy consumption are very small. In other words, energy consumption by itself is not suitable metric to compare energy efficiency. So, we measure the packet delivery throughput of protocols in the networks with limited energy nodes. For same energy consumption there is a significant difference in amount of packet delivery throughput for different protocols. In addition, we measure network lifetime using packet delivery throughput and simulation time.

In Fig. 4, AODV-NC(0.1)-WLB records the highest throughput in every scenario. AODV-NC(0.1)-WLB delivers almost 30% more packets than AODV. It is obvious because AODV-NC(0.1)-WLB delivers 30% more packets than other protocols, as seen in Fig. 7. AODV shows the lowest throughput than the rest. Also, in this figure, we can see that the AODV-NC(0.1) is the first protocol in which a node loses all its power followed by AODV. It means that the lifetime of AODV-NC(0.1) is the shortest among five protocols. Because of overused nodes in AODV-NC, it results in short network lifetime. On the other hand, AODV-NC(1 : 300 – 120) keeps the simulation running approximately 1180 sec without having any node run out of power supply. It means that load balancing techniques in AODV-WLB, AODV-NC(1:300-120) and AODV-NC(0.1)-WLB extend the network lifetime as well as network throughput.

From Figures 3 and 4, we observe that the total energy consumption of all the protocols is almost the same however; the throughput of AODV-NC and AODV-NC-WLB is higher than the original AODV. The throughput measurement that is the metric of number of delivered packets per cut off time explains the efficiency of the protocol clearly.

Fig. 2 shows the energy consumption per delivered data packet and the energy consumption per hop in the scenario of 40 connections which is relatively higher workload scenario in our simulation. AODV-NC protocols use

less energy to deliver a data packet than AODV. Especially, AODV-NC(1:130-200) improves almost 35% in energy saving. Also, for the energy consumption per hop, AODV-NC(0.1)-WLB shows the least energy consumption. From two plots, we can derive that Load balancing technique is effective to save energy in AODV and AODV-NC.

Routing Efficiency. We also compare the routing efficiency with the average number of hops and optimal hops. Optimal hops are calculated by NS2 during the simulation. In Fig. 5, the first plot shows that the average number of hops and optimal hops depending on the cut off time. AODV-NC(1:300-120) delivers packets with the smallest number of hops while AODV uses the largest number of hops. On the other hand, AODV uses the lowest optimal hops among the rest of the protocols. The second plot shows the ratio of average hops to optimal hops in that AODV and AODV-WLB show higher ratio than other protocols while AODV-NC(0.1) shows the lowest ratio. It means that AODV-NC protocols find a shorter path than AODV. The last plot shows the distribution of delivered data packets per hops. In this plot, AODV-NC tends to send packets with smaller number of hops than AODV. AODV uses larger number of hops compared to other protocols. Between 6 and 9 hops, one can see the solid line(AODV) which is above dotted lines(AODV-NC protocols).

Fig. 6 and Fig. 7 compare delivery ratio, routing overhead and end-to-end delay of 5 protocols: AODV, AODV-NC(0.1), AODV-NC(1:300-120), AODV-WLB and AODV-NC(0.1)-WLB. Fig. 6 explores behavior of the protocols when the speed is growing from 1 to 20 m/c. At speed 1 m/s, AODV-WLB increases delivery ratio by 12% but results in increase in relative overhead and delay. However, AODV-NC(0.1)-WLB increases delivery ratio with decrease of relative overhead and delay. At other speeds such as 5 m/s, 10 m/s and 20 m/s, AODV-NC(0.1) shows better performance than AODV-NC(0.1)-WLB. It means that in high mobility scenarios, routing with AODV-NC combined with workload-based load balancing failed to find a path at the first attempt. It causes a node to send route request packets again. As a result, routing overhead as well delay increases.

Fig. 7 explores behavior of the protocols when the number of connections grows from 10 to 60. We fix the maximum speed to 20 m/s. In case of 30 connections, AODV-NC(0.1)-WLB improves delivery ratio and decreases relative overhead. Also, AODV-WLB shows better performance than AODV itself at high workload. As shown in [6], WLB is efficient at the high workload condition. In case of 40 and 50 connections, AODV-WLB improves delivery ratio, relative overhead and end-to-end delay up to 6%, 23% and 7.5% respectively. With AODV-NC, WLB improves delivery ratio, relative overhead and end-to-end delay up to 32%, 85% and 41% respectively. These results are better than AODV-NC itself. It implies that workload-based load balancing technique shows better performance when working

with AODV-NC instead of working with AODV alone especially at the high workload environment.

6. Conclusions

From the energy efficiency point of view, AODV-NC(0.1)-WLB showed the best network throughput and AODV-NC(1:300-120) showed the longest network lifetime by our new metrics. AODV-NC(0.1)-WLB increased throughput almost 30% more than AODV. Also, AODV-NC(1:300-120) and AODV-NC(0.1)-WLB used the least amount of energy per data packet to deliver to the destination and also to jump to the next hop.

In the routing efficiency, AODV-NC(0.1) showed the best performance in relatively low workload scenarios. However, in high workload scenarios, AODV-NC(0.1)-WLB and AODV-NC(1:300-120) showed high performance improvement than AODV-NC(0.1). In 40 connections, AODV-NC(0.1:300-120) found the shorted paths which are close to the optimal hops and used the smallest hops to deliver data packets. Also, AODV-NC(0.1)-WLB improved the performance in high workload environment.

As a result, both non-adaptive and adaptive load balancing techniques combined with AODV-NC showed better performance in energy efficiency as well as routing efficiency. Especially, AODV-NC-WLB showed the best performance in network throughput while AODV-NC(H:t-n) extended network lifetime.

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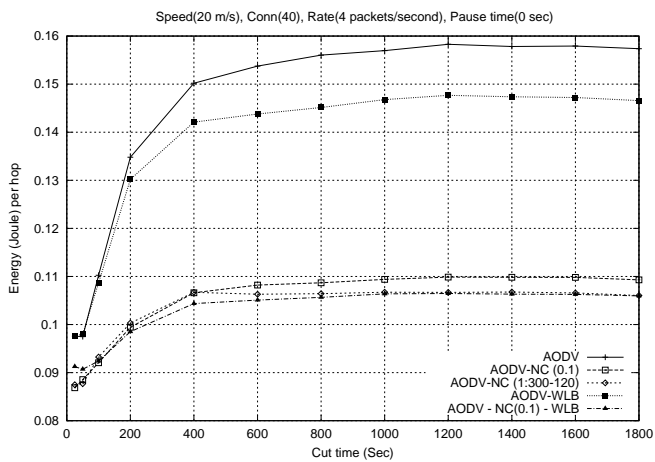
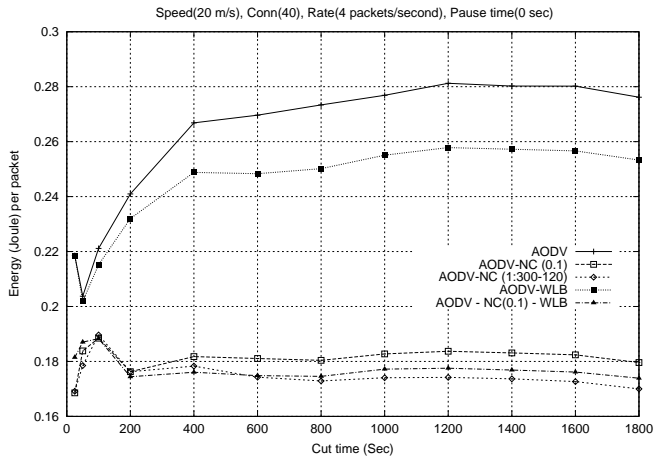


Figure 2. Energy consumption per delivered packet and hop in connection 40.

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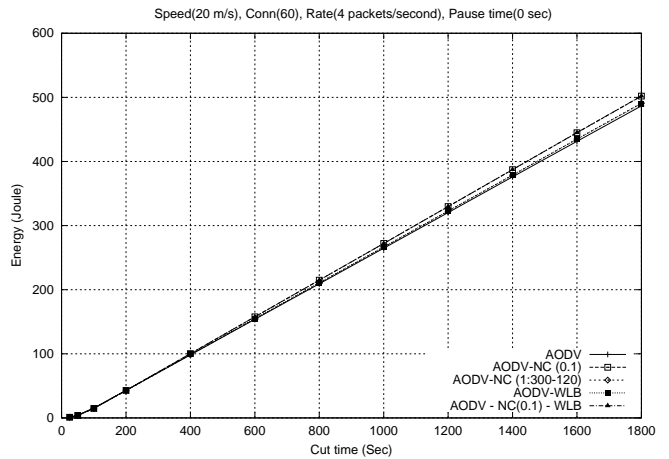
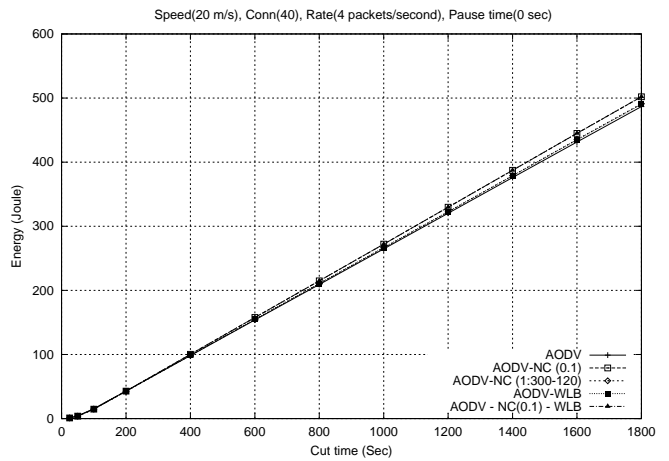
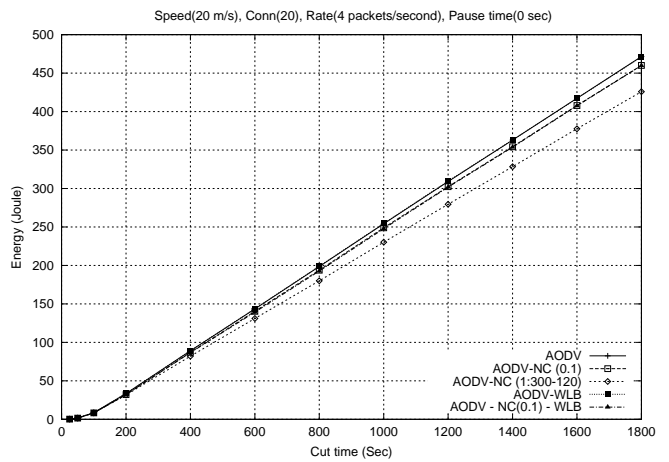


Figure 3. Energy Consumption versus time for connection 20, 40 and 60.

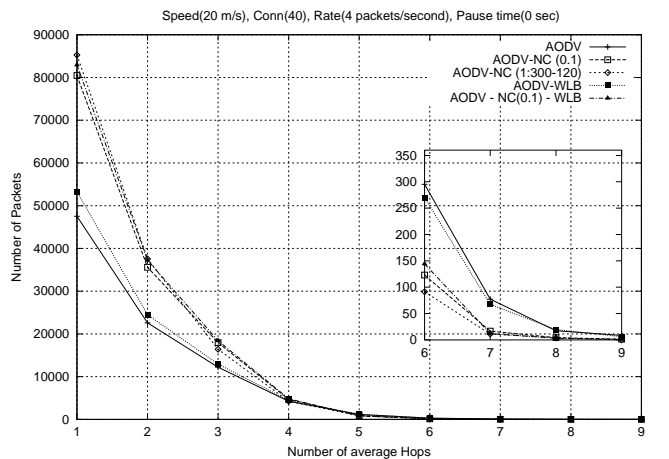
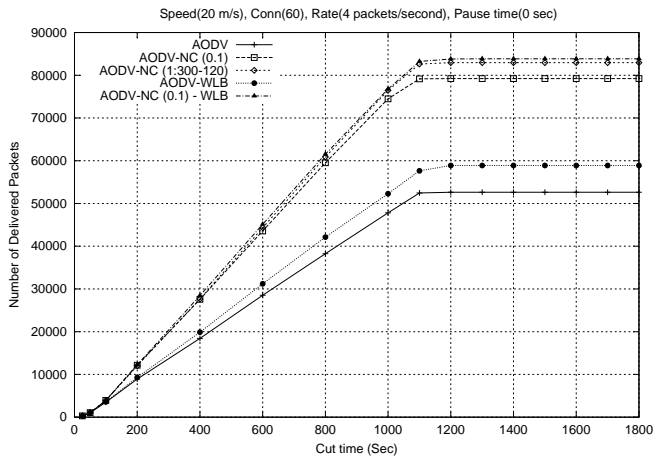
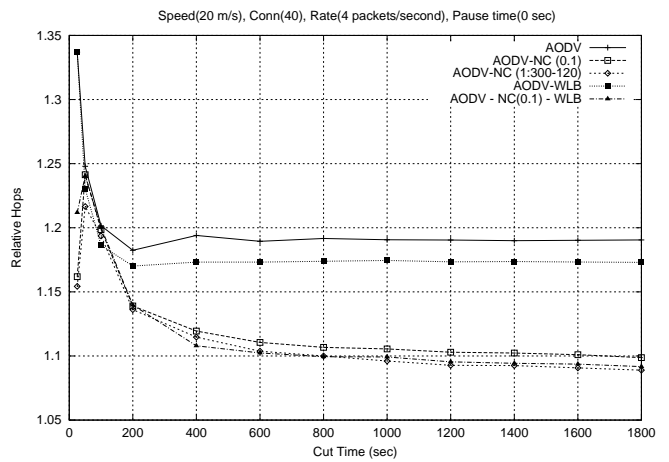
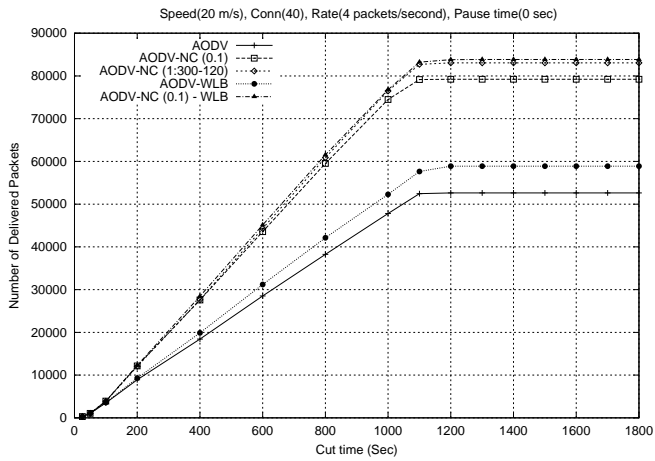
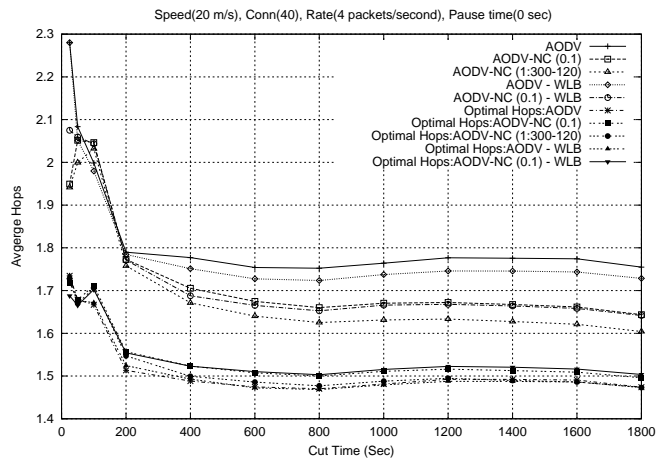
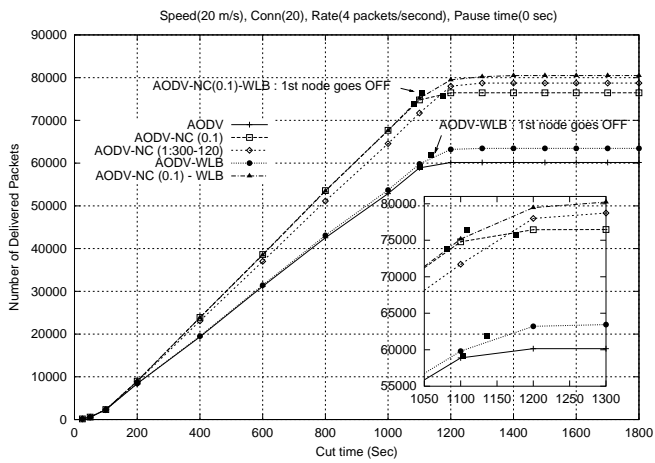


Figure 4. Throughput and Network Lifetime: Cumulative number of the delivered packets with energy 300J for connections 20, 40 and 60.

Figure 5. Optimal number of hops, normalized hops and distribution of average number of hops in connection 40.

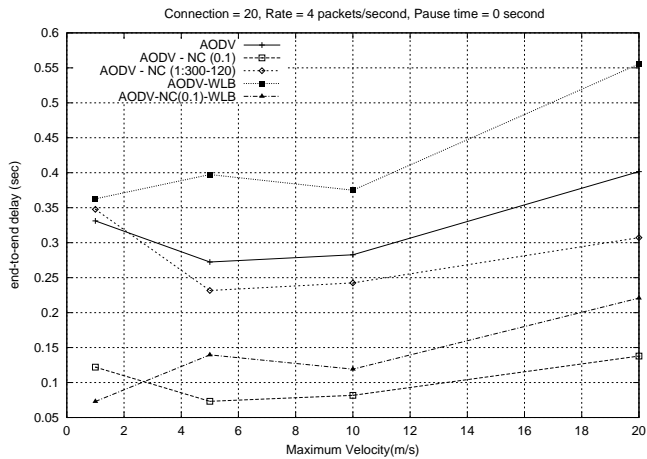
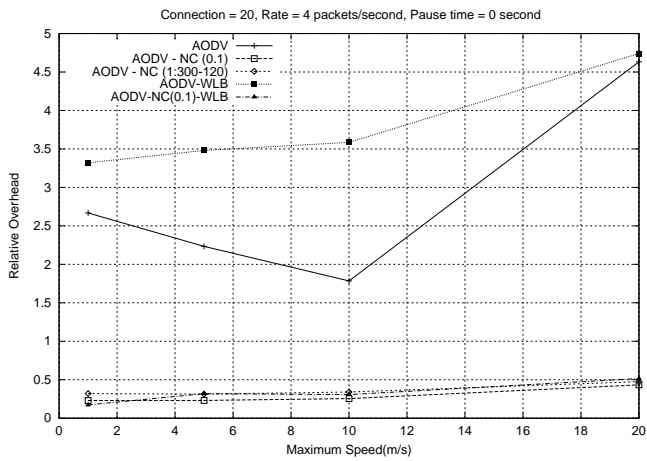
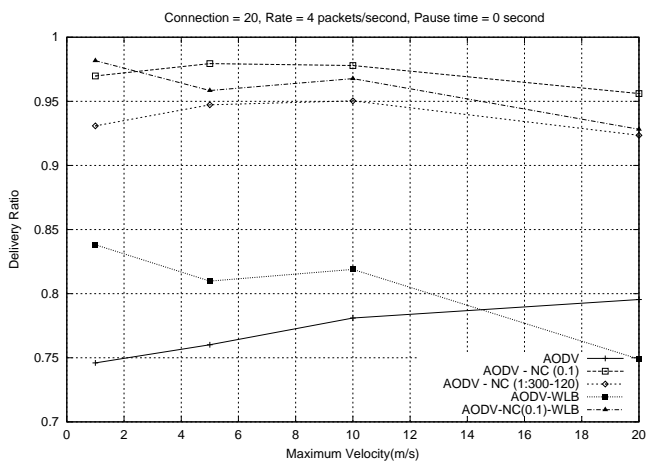


Figure 6. Delivery ratio, routing overhead and end-to-end delay for different velocities.

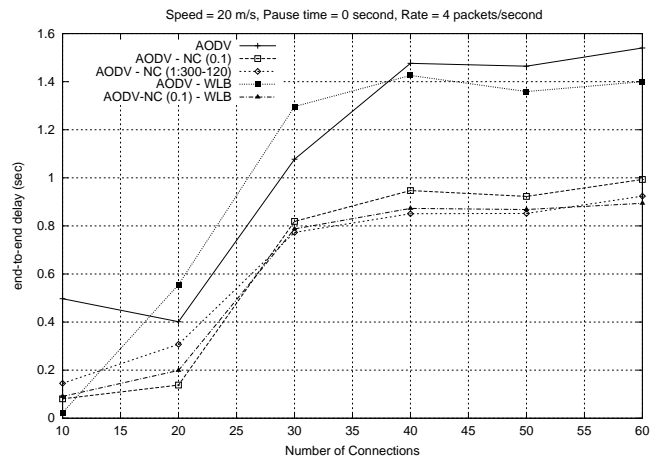
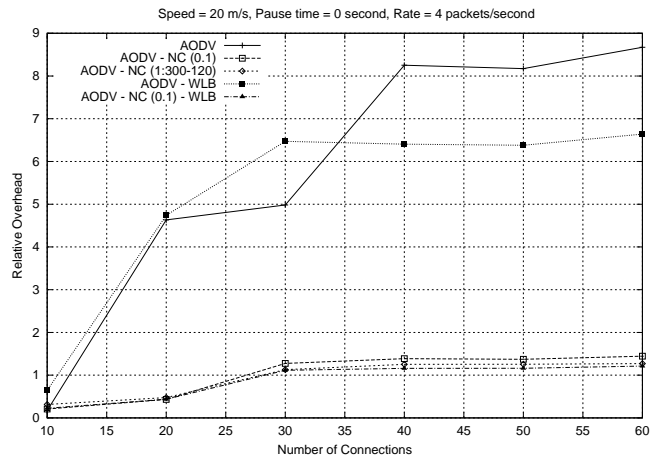
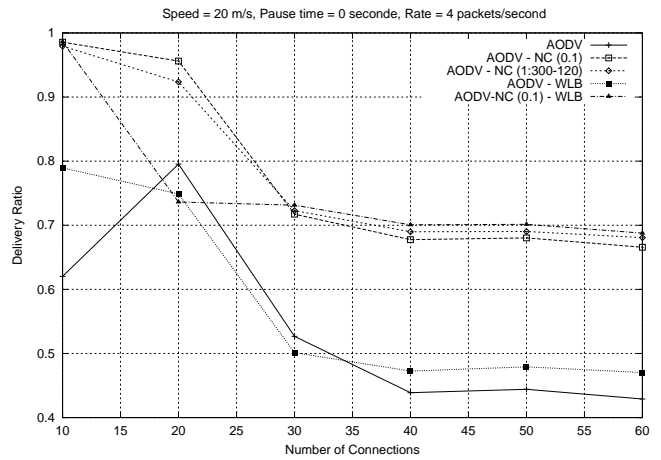


Figure 7. Delivery ratio, routing overhead and end-to-end delay for different number of connections.