# Node Caching Enhancement of Reactive Ad Hoc Routing Protocols

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***Abstract*— Enhancing route request broadcasting protocols constitutes a substantial part of recent research in mobile ad-hoc network (MANET) routing. We suggest a novel approach to constrain route request broadcast which is based on *node caching*. Intuition behind node caching 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 nodes. We cache nodes which are recently involved in data packet forwarding, and use only them to forward route requests. Dropping route request forwarding from the other nodes considerably reduces routing overhead at the expense of possible destination missing. The suggested node caching techniques can be also viewed as a dynamic implementation of a connected dominating set (CDS). We overcome the known drawback of CDS – overuse of dominating (cached) nodes – by a new load-balancing scheme.**

**Our contributions include: (i) a new node caching enhancement of route request broadcast for reactive ad hoc routing protocols; (ii) implementation of AODV-NC, the node caching enhancement of AODV; (iii) an 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; (iv) an evaluation of routing load distribution among MANET nodes; and (v) an implementation and simulation study in NS-2 of forwarding load balancing for AODV-NC sustaining considerable improvement in overhead and delivery ratio.**
**Keywords: routing protocols, mobile ad hoc networks, Ad-hoc On-demand Distance Vector, routing load balancing, performance evaluation, network simulations.**

## I. 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].

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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 minimize energy consumption, 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 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 routing (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. AODV uses periodic neighbor detection packets in its routing mechanism. At each node, AODV maintains a routing table. The routing table entry for a destination contains three essential fields: a next hop node, a sequence number and a hop count. All packets destined to the destination are sent to the next hop node. The sequence number acts as a form of time-stamping, and is a measure of the freshness of a route. The hop count represents the current distance to the destination node. On the contrary, Dynamic Source Routing (DSR) uses the source routing in which each packet contains the route to the destination in its own header and each node maintains multiple routes in its cache. In case of less stressed situation (i.e. smaller number of nodes and lower load and/or mobility), DSR outperforms AODV in delay and throughput but when mobility and traffic increase, AODV outperforms DSR ([5]). However, DSR consistently experiences less routing overhead than AODV. A hybrid protocol enhancing AODV with the advantageous route caching feature of DSR is proposed in [6].

This paper is focused on enhancing route request broadcasting protocols constituting a substantial part of the MANET routing. A simple flooding broadcast for route requests generates a considerable redundant packet overhead which is a major cause of inefficiency of MANET routing protocols. Several broadcasting techniques are compared in [7] and [8] concluding that neighbor-knowledge based broadcasting is better then probabilistic and area based methods in reducing packet redundancy. Another interesting approach constrains the number of detours or deviations from the known routes resulting in 50% overhead and delay reduction but insignificant decrease in delivery ratio for DSR [9]. The AODV protocol has been enhanced in [10] by pruning dominant nodes, i.e. effectively constraining route requests to a certain connected dominated set.

In this paper we suggest a novel approach to constrain route request broadcast which is based on *node caching*. Our 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. We cache nodes which are 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, we drop route requests forwarding from the nodes which are not cached at the expense of possible destination missing.

Our node caching techniques can be also viewed as a dynamic implementation of a connected dominating set (CDS) based routing. Indeed, the cached nodes are supposed to cover the recent sources and destinations and are mostly connected by recent intersected paths. The known drawback of CDS is overuse of dominating nodes. We suggest to measure the protocol fairness using parameters of forwarding load distribution among MANET nodes. We confirm that node caching may cause unfair forwarding load distribution and propose a load-balancing scheme for fixing this drawback.

Our contributions include:

- A new node caching enhancement of route request broadcast for MANET reactive ad hoc routing protocols;
- An implementation of AODV-NC, the node caching enhancement for AODV;
- An extensive simulation study of AODV-NC in NS-2 showing that in case of highly stressed MANET the routing overhead is reduced by average 90%, the delivery ratio is increased by average 20%, and the end-to-end delay is decreased by average 63%;
- An evaluation of routing protocol fairness measured as distribution of forwarding load among nodes;
- An implementation and simulation study in NS-2 of forwarding load balanced AODV-NC sustaining considerable improvement in overhead, delivery ratio and delay over the standard AODV.

The rest of the paper is organized as follows: in the next section we describe the node caching and the AODV-NC protocol. Section III describes the simulation study of forwarding load distribution and suggests load-balancing modification of AODV-NC. In section IV we give the results of our simulations in NS-2 comparing original AODV, AODV-NC, and forwarding load balanced AODV-NC protocols.

## II. Node Caching Enhancement of Route Request Protocol

In this section, we describe node caching enhancement of route request broadcasting in reactive ad hoc routing, give implementation details of node caching AODV (AODV-NC) and present simulation results illustrating the hit ratio and the size of node cache.

As mentioned in the previous section, we want to cache connected and dominating set of nodes that have updated information about their neighbors while wasting no resources for finding and maintaining the cache. All these requirements are very well satisfied by the nodes which have recently forwarded data packets. Indeed, a union of source-destination paths with multiple intersections is well connected and dominates almost all nodes since such nodes are mostly in the center of the network. Of course, such set does not require any maintenance.

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.

In the default settings of AODV, if the route to the destination is broken, obsolete or unestablished, the route request originated from the source is propagated through the entire MANET. If the route reply is not received by source in a certain period of time, then the route request is periodically repeated several times. If all these Route Requests happened to be unsuccessful, several more requests with increasing time gaps are sent.

In our implementation, we tried to avoid drastic changes to the very well established AODV protocol. We restrict

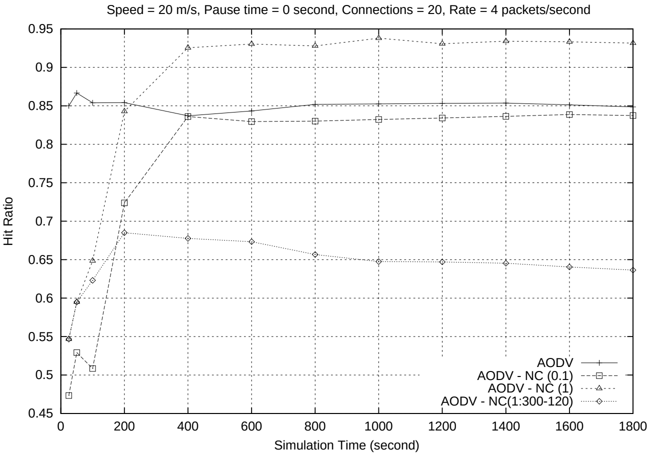


Fig. 1. Average success rate of cache-constrained route requests.

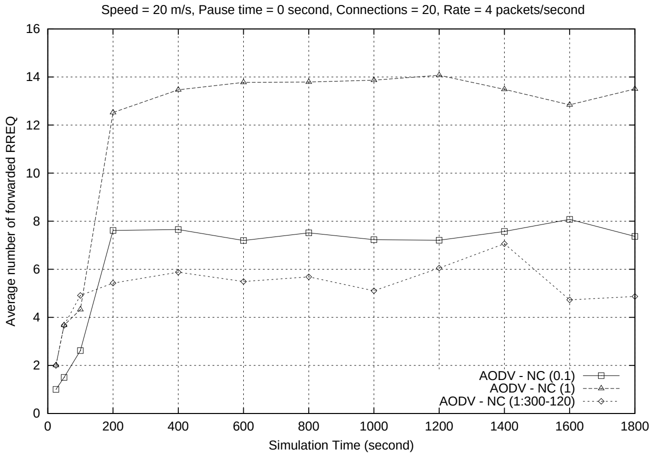


Fig. 2. Average number of forwarding nodes per cache-constrained route request.

modifications solely to the Route Request protocol and its initiation.

**Route Request in AODV-NC(*H*)**

(1) If a requested route is not available, then send an *H*-restricted route request with the threshold *H*, i.e., for each route request recipient *N* do
   - if the destination is the known neighbor of *N*, then *N* forwards the route request to the destination
   - if no more than *H* seconds are gone from the last time a data packet has been forwarded by *N*, then *N* rebroadcasts the route request to all its neighbors

(2) Repeat *H*-restricted route request 2 times if route reply is not received during time 0.3 sec after route request

(3) If no route reply received, then send unconstrained (standard AODV) route request with the standard repetition pattern.

We did not attempt to find the best initial threshold *H* theoretically. Our simulations show that on average the best choices of *H* are between 0.1 sec and 1sec. If we would know in advance MANET parameters, then we can tune threshold more carefully – higher traffic intensity and mobility level correspond to the smaller threshold.

The value of *H* directly affects the hit ratio of the node cache, i.e., the fraction of cache-constrained route request attempts succeeded to find the destination over all cache-constrained requests. Fig. 1 illustrates our simulations with different values of *H* - larger *H* corresponds to larger hit ratio. The value of *H* is also inversely proportional to cache size, average number of nodes forwarding a route request (see Fig. 2). Note that the standard route request will be forwarded by all nodes except source and destination.

## III. Routing Protocol Fairness and Forwarding Load Balancing

In this section, we discuss fairness of routing protocols, show how fairness and network lifetime can be measured, compare AODV and AODV-NC protocols and suggest a load-balancing scheme increasing lifetime and improving fairness of AODV-NC.

As we have mentioned in Section I, the node cache can be viewed as CDS. While being very efficient, CDS-based protocols can overexploit the nodes which belong to CDS. This results in reducing *network lifetime*, i.e., time between beginning of operation and the first node exhausts its batteries (assuming, e.g., equal battery supply for all nodes). We can also look at this phenomenon from *fairness* prospective as follows[1]. Each node by joining an ad hoc network is required to support multi-hop communication, i.e., forward data and control packets upon request. If certain nodes are unlucky enough to forward too many of such packets, then they can claim unfairness of the network protocol and drop membership. Note that it does not matter how many packets are *generated* by a node – if a node sends too many packets, then it is fair that such node pays the corresponding energy amount. Only forwarding load is fair to account for.

In order to measure unfairness, we suggest to look at the ratio of the maximum forwarding load among individual nodes over the average forwarding load. Note that the absolute value of the maximum forwarding load is also important – if the network lifetime is considerably larger for one protocol than for another, then fairness ratio loses its relevance.

[1]The first attempt to measure fairness of CDS-based routing uses a different approach [10].

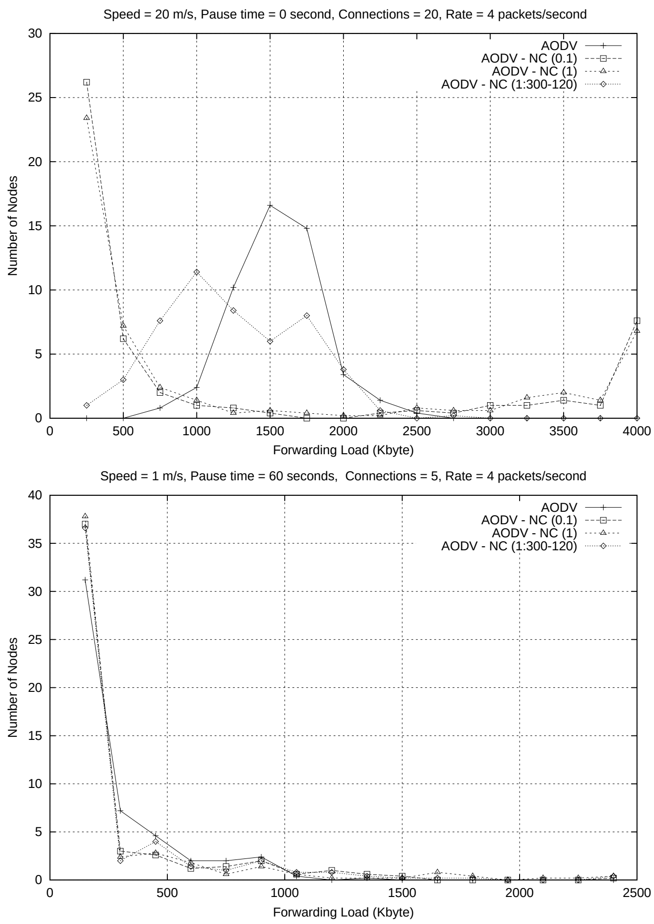


Fig. 3. Distribution of the forwarding load among nodes for high (top) and low (bottom) traffic and mobility.

Fig. 3 illustrates distribution of forwarding loads among 50 nodes for several protocols – the range between 0 and 4000 Kbytes is partitioned into 250 Kbytes subintervals and the number of nodes forwarding the load from each subinterval is reported. We can see that AODV is fair – its fairness ratio is below 1.7 – while AODV(1) and AODV(0.1) are unfair because of a bump at 4000. Also the lifetime of new protocols is 1.6 times shorter than AODV's.

In order to prevent unfairness of node caching we should relieve nodes which stay in cache for too long time. Several geometric models have been proposed [11] [12] to impose load balancing. Our simple scheme balances the control and data packet forwarding load without using geometric knowledge of the network. We suggest a load-balancing scheme 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 we relieve 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 $N$. In Fig. 3, one can see that AODV-NC$(1 : 300 - 120)$ is almost as fair as AODV and has longer lifetime.

## IV. 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 rectangle. The basic rectangle is 1000m×300m, but we also repeated simulations for 1500m×300m and 1000m×1000m rectangles. The maximum simulation time was 1800 sec but we have recalculated the basic parameters each 250 sec. 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 [13]. 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 50. Data packet size is 512 bytes and control packet size is 48 bytes. All traffic scenarios are generated using *cbrgen.tcl* in NS-2.

**Performance 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.

**Simulation Results**. All results are the average of 5 different scenarios which have different values of seed numbers – 1500, 2000, 2500, 3000, 3500. We experimented with different threshold values of H = 0.01, 0.05, 0.1, 1,5, and 10 for AODV-NC(H) and found that H = 0.1 and 1 demonstrate the best performance.

Fig. 4 and Fig. 5 compare delivery ratio, routing overhead and end-to-end delay of 4 protocols: AODV, AODV-NC(1), AODV-NC(0.1), AODV-NC(1:300-120). Fig. 4 explores behavior of the protocols when the speed is growing from 1 to 20 m/c. All three proposed node caching protocols increase delivery ratio by 10-20% and reduce overhead by factor 10. The delay reduction for unfair protocols AODV-NC(0.1) and

AODV-NC(1) is 3-4 times while the fair protocol AODV-NC(1:300-120) has mere 10-20% delay reduction.

Fig. 5 explores behavior of the protocols when the number of connections is growing from 10 to 50. Unfair AODV-NC protocols (respectively, the fair AODV-NC(1:300-120) protocol) increase delivery ratio by 20% (respectively, 15%) and reduce overhead by factor 7 (respectively, 3). The delay reduction for the unfair protocols AODV-NC(0.1) and AODV-NC(1) is 40% while the fair protocol AODV-NC(1:300-120) has mere 25% delay reduction.

We also simulate all 4 protocols in different rectangular regions – $1000\times1000$ and $1500\times300$. In all our simulations all NC protocols improved AODV in all three main parameters except for square region, where AODV is better than the fair AODV-NC(1:300-120). Average improvements are practically the same as for $1000\times300$ rectangle.

We have also compared all 4 protocols for the case of high mobility and low traffic with intention to make node cache useless. Even in this case the routing overhead has been reduced and the delivery ratio has been increased while the only loss to AODV has been found for the delay.

Separately we compared our protocols with AODV-PA [6] on comparable test cases – while the both protocols have the same as AODV delay, AODV-NC(1:300-12) improves delivery ratio of AODV-PA by 7% and has considerably larger routing overhead reduction (80% vs 19%).

In conclusion, on average our fair forwarding-load balanced AODV-NC protocol compared to conventional AODV improved routing overhead by 89%, delay by 20%, and delivery ratio by 17%. These improvements are in general larger than for the best-to-date protocol AODV-DS recently proposed in [10] which also considerably improves routing overhead (by 70%), but only slightly improves delivery ratio (by 5%).

## V. Conclusions

In this paper we introduce a novel node caching approach for constraining the route request protocol in ad hoc routing. We have implemented node caching enhancement AODV-NC of AODV which improves the original AODV in all three metrics – extensive simulations in NS-2 show average decrease by 90% in communication overhead as well as average decrease by 63% in the delay, and average increase by 20% in the delivery ratio.

We have also proposed a new measure of fairness of ad hoc routing protocols which depends on distribution of the forwarding load among nodes. The AODV-NC protocols are shown to be unfair and make certain overused nodes to exhaust their batteries prematurely. We also suggest a load-balancing scheme that improves fairness and lifetime AODV-NC sustaining considerable improvement in overhead, delivery ratio and delay over the standard AODV.

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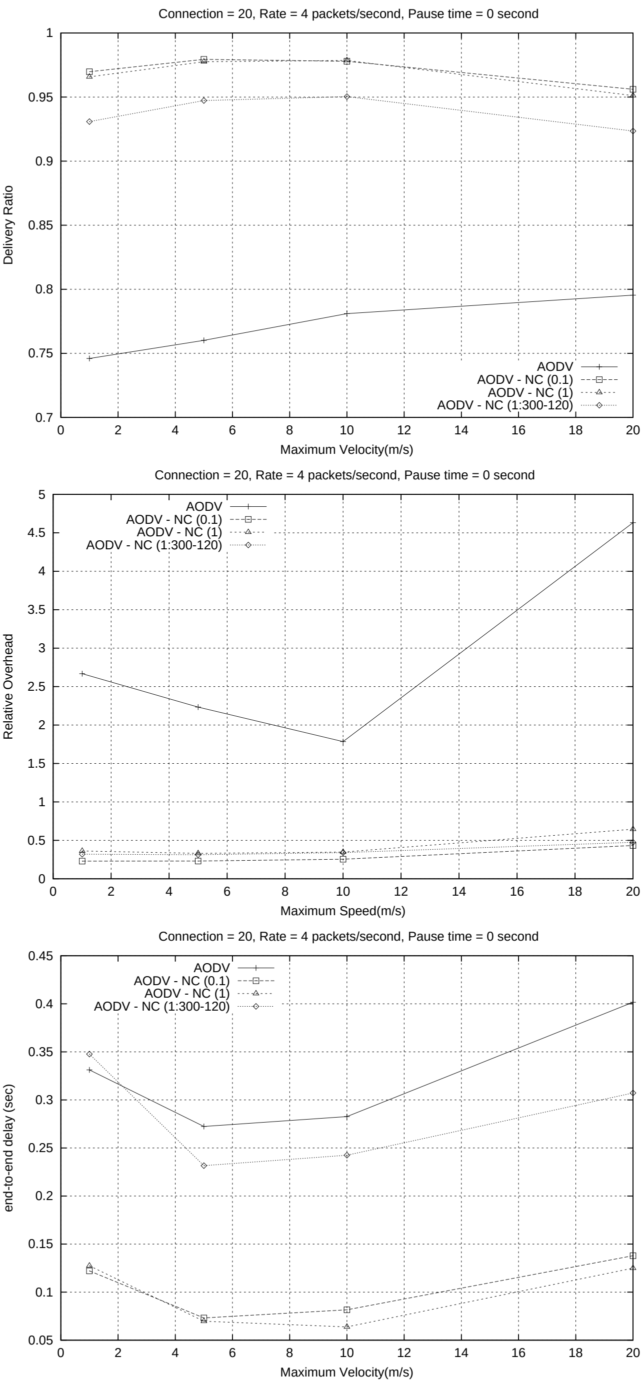


Fig. 4. Delivery ratio, routing overhead and end-to-end delay for different velocities.

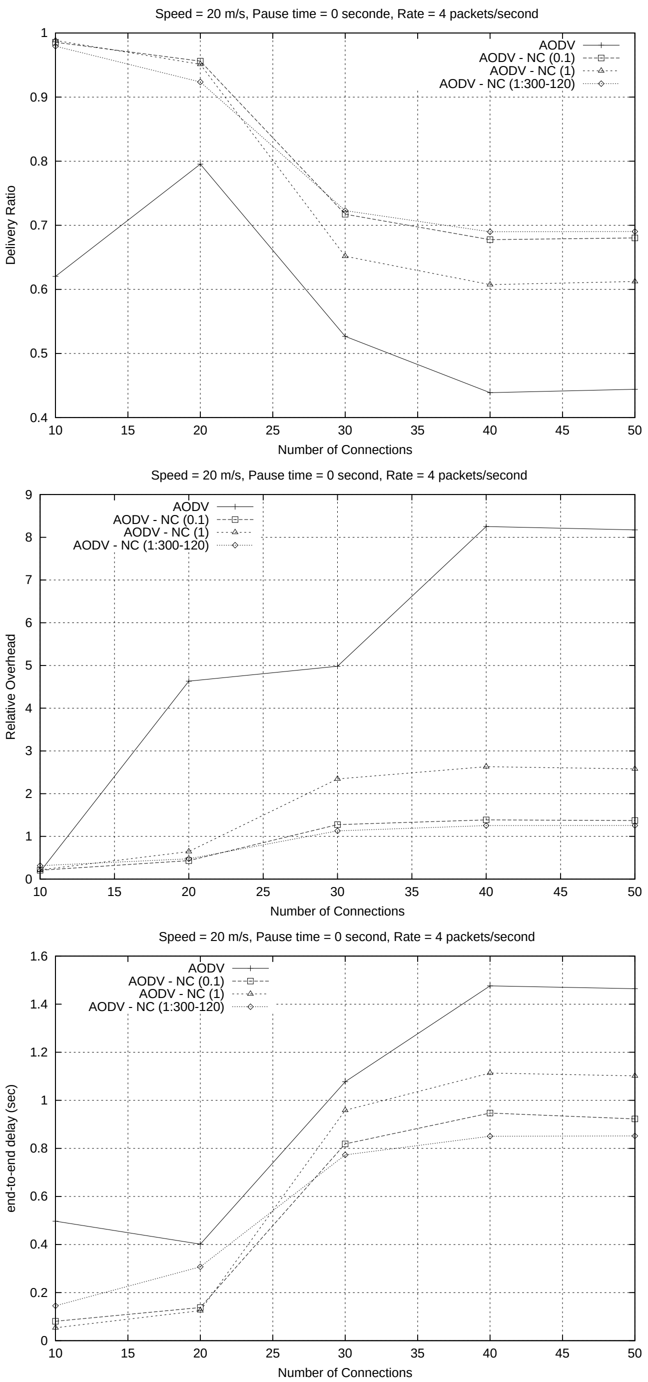


Fig. 5. Delivery ratio, routing overhead and end-to-end delay for different number of connections.