Simulation of the HikerNet

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Abstract

HikerNet is a store-and-forward messaging system for areas without ordinary communication infrastructure. The transport of the messages is accomplished by devices that are carried around. When devices are in close range to each other, messages can be exchanged based on peer-to-peer connections in an ad-hoc network. The messages are sent asynchronously in a store-and-forward pattern. We have implemented a simulation for HikerNet. Results and conclusions from simulations of the HikerNet are presented in this document.

1 Introduction

HikerNet [Lei04] is a message forwarding service based on ad-hoc communication between devices which are carried around. The transport of the messages is accomplished by devices, here denoted as transport nodes (TN) that move with their bearers, and span the infrastructureless parts. The devices can exchange messages at close range based on peer-to-peer connections in an ad-hoc network. HikerNet is designed for enabling communication in areas where no ordinary infrastructure for communication is available, e.g., sparsely populated areas where people are in motion. As a use case we mention remote mountain areas without major routes, e.g., the Hardangervidda, a mountain area in Norway during tourist season.

We have developed a simulation tool to evaluate the feasibility of the HikerNet. For our simulation we use the Hardangervidda which is a popular area for hiking, and which does not have sufficient coverage of other communication infrastructures.

The important properties of the HikerNet to be simulated include long time between the meetings of the TN, rather slow transport of the devices, and thus long delivery times of several days.

The HikerNet consists of two types of TNs: the H-nodes, which are the sending and receiving devices belonging to a dedicated user, and the N-nodes, which are anonymous transport nodes. The message transport is based on the movements of the TN. During encounters of hikers messages are exchanged between the respective TNs.

The operation of the HikerNet can be controlled by several parameters in every TN (e.g., TTL, TTR, and EXP). These parameters hav an influence on transport time, percentage of lost messages, or memory usage. Each message has a TTL (times-to-live) value, that defines the maximum number of hops. Messages where TTL has reached the value 0 are not propagated to other TN (except to the final recipient). When a TN is carried to another

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location the value of TTL is not changed. TTR defines how often a message is replicated at one TN, while EXP defines after which date the message is removed from the network.
The HikerNet has an acknowledgement mechanism in order to remove messages, which have arrived at the recipients node. After a message has arrived at the receiver's H-node, an ACK message is sent from this TN, and forwarded in the same manner as ordinary messages. A TN which receives an ACK message removes the original message.
Messages to be sent in the HikerNet are supposed to be text messages or MMS messages of some 50 kBytes. The memory size of the TN is supposed to consist of some megabytes. Security and confidentiality issues of the HikerNet are beyond the scope of this paper since they do not influence the simulation. We do not take extensions of HikerNet (e.g., gateways to other services, or bridges) into account which are described in [Lei04]. In our simulation we do not support senders or recipients outside the area simulated area.
In the remainder of the paper we show in Section 2 the principles used for the simulation of HikerNet, how the HikerNet was modelled, and notes on the implementation. In Section 3 we present the simulation results for the basic operation of HikerNet using two different movement patterns for the hikers, and additionally stationary TN. Section 4 concludes the paper and interprets the simulation results.

2 Simulation of HikerNet

For the purposes of our simulation we use the network of cabins and paths of the Hardangervidda in Norway. The Hardangervidda is the largest mountain plateau in Europe of about 8000 km^2, which is a popular area for mountain hiking. There are about 50 cabins with about 15000 registered stays overnight during the three-months summer season[1]. GSM services are only available along the roads and railroads. An illustration of the chosen area is given in Figure 1.
We used the Hardangervidda in order to make a first evaluation of the feasibility and usefulness of HikerNet. Using the basic transport mechanism of the HikerNet, the average transport time of a message will be in the size of some days, since the messages cannot be transported faster than it would take for a person to deliver the messages personally. Assuming about 1000 hikers in the area at the same time[2], who each sends 10 text messages a day with 2 kBytes each with an extra overhead of 1 kBytes of header information, the memory size of each transport node is about 3 Mbytes. Assuming MMS messages (about 50 kBytes per message) to be delivered the memory size needed in a TN would be about 50 Mbytes.
We simplify the simulation by using the following assumptions: The hikers exchange messages only at the cabins once a day. When meeting on the paths between cabins no messages are exchanged. Encounters on the paths between cabins would just transport the message back to the cabin where it came from, and would be similar to having stationary nodes at the cabins. The hikers walk from a cabin to a neighbouring cabin during one day, even

[1] The numbers are taken from the annual report of Den Norske Turistforeningen, `http://www.turistforeningen.no`. During the winter-season around easter about 5000 stays overnight are registered.
[2] This number is realistic for some days in the high season.

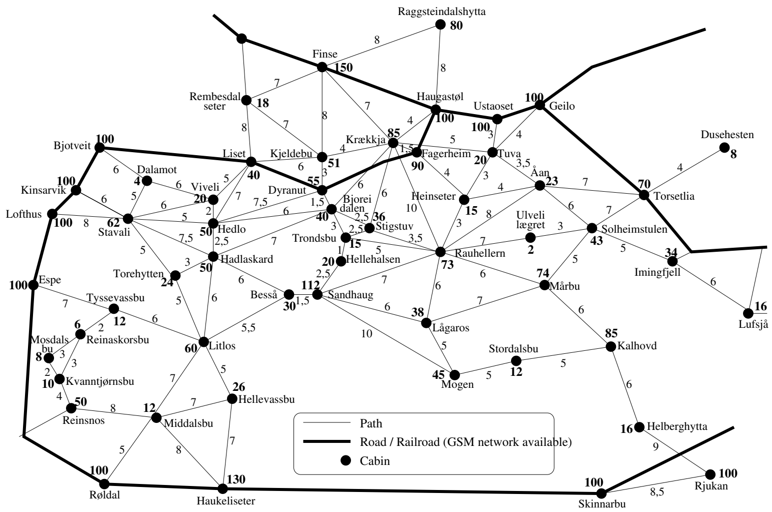


Figure 1: Graph of cabins and trails on the Hardangervidda in Norway. The TN are moved along the paths which are marked with the number of hours a passage would take for a hiker. The cabins are marked with the number of available beds.

though in reality it is possible to reach other cabins.

In the mountain-scenario, we have restricted the information exchange between TNs to locations where people meet as a worst-case assumption. However, in reality information exchange between devices can also take place while walking (two people meet in the path), or when some proximity conditions arrive (somebody passes near a tent). Additionally, the devices can also be carried outside the defined edges. These assumptions would speed up message delivery to some extent.

While it is sufficient to simulate exchange of messages once a day in a scenario in the mountains, a scenario in a city would make different assumptions necessary: People meeting in the streets would lead to much smaller time steps, and different movement patterns of citizens.

The simulation is performed by modelling the movements of the hikers carrying the TN and calculating the locations where hikers meet, and the TN exchange messages. By simulating the movements of the TN we get a script of events, which denotes the potential exchange of messages, which is translated into calls of a prototype of HikerNet. This script is run with varying parameters for HikerNet nodes, and the results are extracted from the log-files. These results give hints on how many TN are necessary (critical mass), transport time, number of hops, memory usage, suitable values for parameters like TTL, TTR, and EXP.

For our purposes we need the encounters at the cabins which result in the exchange of messages. We implemented two possibilities for hiker movements: equal distribution (the hikers move randomly between cabins) and taking the size of the cabins into account (the number of available beds is used for deciding where the hikers move).

2.1 Modelling of movements

For the simulation of mobile ad-hoc networks the movement of the participating TN is necessary. Most models use continuous movements in a topology of networked routes. Both synthetic models and models based on observations of the real behaviour are used for simulations of mobile ad-hoc networks. Since we do not have observations for ad-hoc networks we use simulations for modelling the movements. Several parameters for modelling the movements are vital, e.g., whether the TNs move dependently or independently of each other. Newer research states that using the different mobility models can give severe differences in the final result [Tra02].
For TNs that move independently the "Random Waypoint Mobility Model" [Jos98, JM96] is used. This model is based on TN moving from vertex to vertex in a topology, with a pause of varying duration at each vertex. Group based models are used when individuals move in groups (rescue actions, military troops movements), e.g., "Reference Point Group Mobility" (RPGM) [Xia99]. Then the individuals move in a random pattern around a central movement point of the group. However, for the simulation of the HikerNet this is irrelevant, since the kind of movements in RPGM is rather atypical for hikers.
While many contributions in the literature of mobile ad-hoc network simulations are based on rather small areas with a dense population of individuals, the HikerNet is designed for mountain areas with large distances between the TNs, and rather low population and low speed. Movement simulations for the latter case has been done in AlpSim [Chr03] and RBSim [H R01]. These systems are based on independent agents that simulate the movements of hikers in mountain areas. These simulators take into account that some areas are more interesting for the participants in the network than others.
For the modelling of the HikerNet the goal is to get a realistic movement pattern of the TNs, rather than getting the exact numbers of hikers at each cabin. The simulation of the movement is used as a basis for the further simulation using the communication patterns.
The simulation is done with three different traffic patterns:

(a) All TNs are in movement. When taking the decision where to a hiker moves in the next time step, all neighbouring cabins are considered equally distributed.

(b) All TNs are in movement. When taking the decision where to a hiker moves in the next time step, the probability is dependent on the number of beds in the target cabin.

(c) Additionally, stationary TNs are introduced, one at each cabin.

2.2 Modelling of HikerNet

We describe HikerNet formally as a basis for the simulation.

(a) A set of locations $c_i \epsilon C$ where the hikers meet. In our scenario these locations might be cabins, train- and bus-stations, lodges, etc.

(b) When there is a path for hikers between the locations c_i and c_j they are connected by an edge $p_{ij} \epsilon P$ in our model.

(c) A TN $d\epsilon D$ is attached to a hiker. A device d is transported along the edges $p_{ij}\epsilon P$. The devices exchange messages at the locations $c_i\epsilon C$.

(d) A message $m_k\epsilon M$ with the message ID k is transported via several edges using one or several the transport devices.

(e) The message is transported between sender S and receiver R. Note that the location of the receiver may change during time, i.e. is not attached to one $c_r\epsilon C$, except for stationary TN.

The model of delivering messages by the HikerNet is related to movements of hikers in a network of paths between lodges. Therefore, we first model the movements of the hikers, and use the results of this as a basis for the simulation of the message transportation.
The forwarding algorithm is as follows:

- A message m_k is initiated at device d_s with the destination address d_r.
- A message m_k on device d_m spreads to all devices in contact with d_m at the vertex c_i. A message m_k is stored only once in one device.
- A device d_h at location $c_i$is carried along edge p_{ij} to location c_j in one time step, where the next information spreading takes place. The choice of $p_i j$ is according to the waypoint model; see Section 2.1.
- When a message arrives at the recipients node d_r, an acknowledgement message a_k is sent out, marked with the same message ID k as the original message.
- When an acknowledgement message arrives at a device d_h, the original message is deleted. The acknowledgement message is kept in d_h until the message is expired.
- Messages expire after a certain number of time steps. Expired messages are deleted from the devices.

2.3 Simulation

The simulation model was performed using a prototype implementation of the HikerNet written in C. The simulation of the movements of the hikers, generation of meetings and control of the simulation is implemented in Python.
The simulation is performed on a PC running Linux, where each TN is stored in one dedicated directory. This results in rather large I/O-activity, which made it necessary to implement the TN in a ramdisk in order to keep the simulation time low. Nevertheless, the simulation time is in the size of several hours for 500 TN over 14 time steps.
Simulations presented here are performed with a number of messages at the start and no new incoming messages during the simulation. We have also performed simulations where new messages are created at every time step. Since there are no limitations on memory usage, and messages do not influence each other, this only had impact on the memory usage, while the other results were the same.

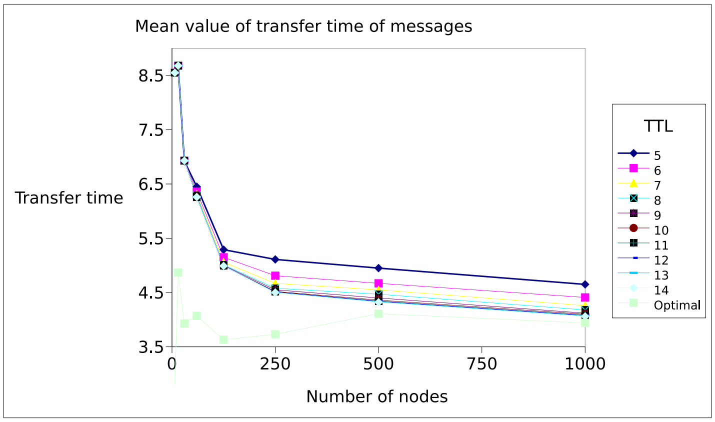


Figure 2: Mean value of transfer time of messages.

3 Simulation Results

The simulations results are based on random hiker movements, weighted hiker movements, and the introduction of stationary TN into the HikerNet. Additionally, the optimal values are shown in the graphs, i.e., the shortest possible delivery time, or the highest possible percentage of arriving messages.[3]

3.1 Random hiker movements

The following results are based on random hiker movements.

Result 1 (Figure 2) *The mean value of the delivery time*[4] *of a message decreases when more TN are in the system.*

When more TN are in the system it is more probable that all possible paths are used by hikers. Note that the optional value is not reached even when 1000 TN are in the system. The optimal value for the delivery time for a low number of TN is dependent on coincidences, and is therefore difficult to interpret.

Result 2 (Figure 2) *For more than 60 TN we observe that higher TTL values reduce mean value of the delivery time. For TTL values larger than 10 the influence to the delivery time is negligible.*

Result 3 (Figure 3) *The mean value of the number of jumps until a message arrives increases for larger values of TTL, while the delivery time is reduced. The mean value of the number of jumps until a message arrives increases when more TN are in the network.*

[3] Since the hiker movement is calculated independently for each number of TN, and is dependent on the topology of the network, the optimal value has a somewhat random behaviour for low numbers of TN.

[4] The delivery time is defined as the number of time steps from sending a message until arrival at the recipient.

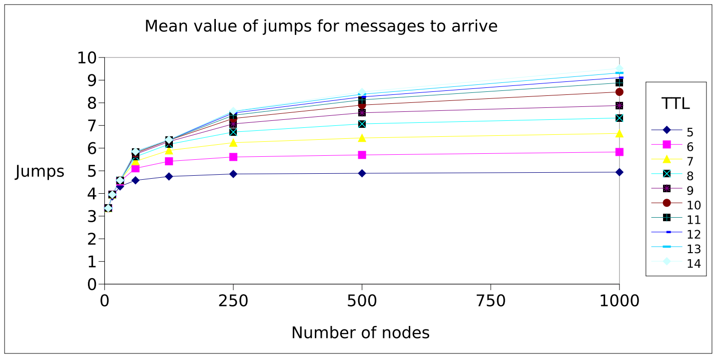


Figure 3: Mean value of jumps for messages to arrive.

For higher values of TTL there might be faster routes with more jumps. Therefore, this result is an indication of faster delivery for higher values of TTL. Additionally, several “unnecessary jumps” in the cabins could contribute to this result, which at lower TTL can lead to the message not being delivered.

Result 4 *The mean value of the delivery time converges towards a value of about four time steps during simulated 30 days.*

Result 5 (Figure 4) *The fraction of messages arriving at the receiver increases when the number of TN increases. For more than 250 TN the diagram flattens.*

Result 6 (Figure 4) *Higher TTL gives a higher percentage of messages arriving for more than 60 TN. TTL values larger than 9 do not have much influence on the arrival rate.*

For more than 500 nodes the percentage of arriving messages is close to the optimal value for higher TTL values (> 7).

Result 7 (Figure 5) *For TTL=9 and 250 TN the percentage of messages arriving is as follows: 35% after four steps, 84% after seven steps, 99% after 10 steps and 100 % after fourteen steps.*

Result 8 (Figure 6) *The memory usage increases fast for increasing number of TN. For more than 250 TN the curve flattens, and is nearly constant. The memory usage increases for higher values of TTL.*

Result 9 *The mean value of memory usage in a device increases until simulation time step 6, when 73% of the messages have arrived. Thereafter the memory usage decreases when the ACK-messages arrive and messages are removed from the TN. The number of messages and the memory usages depend on each other.*

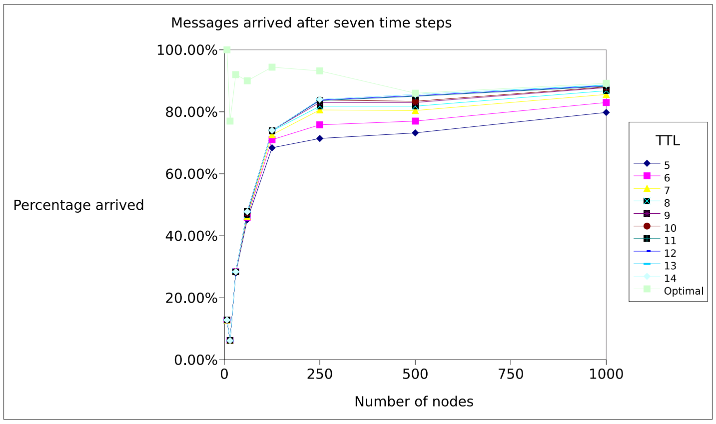


Figure 4: Messages arrived after seven time steps.

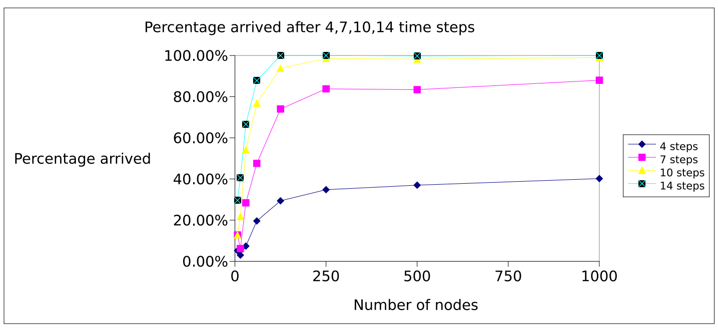


Figure 5: Messages arrived after time steps with TTL=9.

3.2 Weighted hiker movements

In the scenario with weighted movements, the number of beds at the cabins is used for modelling the movements of the hikers. We calculate the ratio of the simulated values and the corresponding optimal values for delivery time and arrival percentage.

Result 10 (Figure 7) *For low numbers of TN, and low TTL values the weighted movement pattern shows slightly better results, while there are no significant differences otherwise.*

Using the weighted movement pattern the majority of hikers will concentrate in some main areas giving better communication conditions, while the other areas are still covered, but with a lower number of hikers than before.

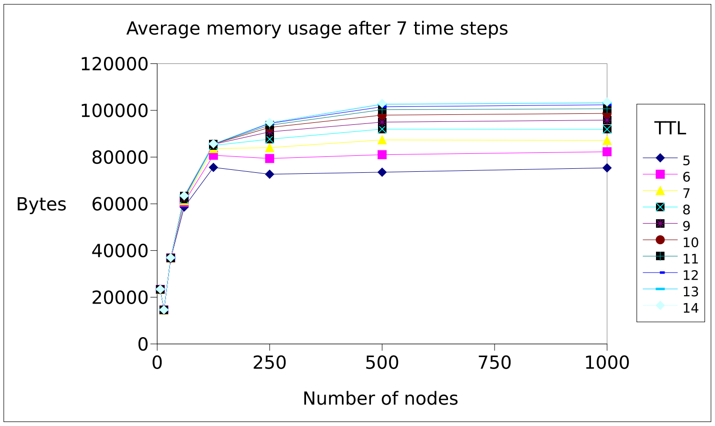


Figure 6: Average memory usage after 7 time steps with different TN and TTL.

3.3 Stationary TN

We simulated the impact on installing one stationary TN at each cabin. We calculate the ratio of the simulated values and the corresponding optimal values for delivery time, arrival percentage, and number of jumps.

Result 11 (Figure 8) *Using stationary TN the transfer time is lower when the number of TN is lower than 500; small impact else.*

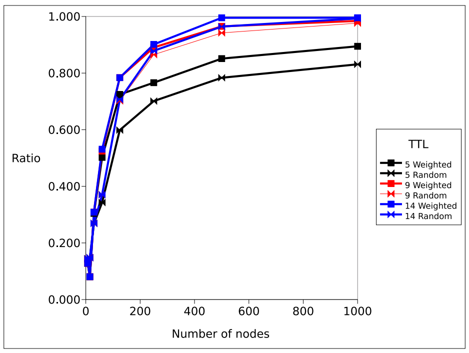
Result 12 (Figure 9 a) *Using stationary TN the percentage of arriving messages is higher when the number of TN is lower than 125; only small impact else.*

Result 13 (Figure 9 b) *Using stationary TN the number of jumps increases slightly.*

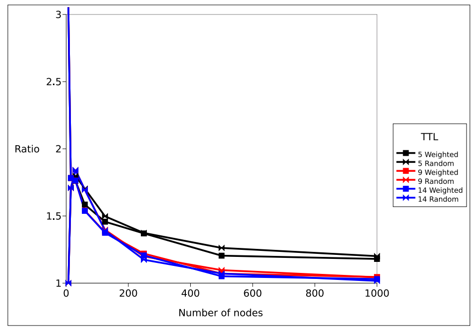
We conclude that the introduction of stationary TN gives a slightly better performance of the HikerNet, especially when the number of TN is low.

4 Conclusions and Further Work

The simulation of the HikerNet gave us several hints of its operation conditions. The results show that the HikerNet operates feasibly when more than 60–100 TN are active, which corresponds to about 2–3 times the number of cabins. The results show also that the mean value for the delivery time is about four days, when only a third of the messages have arrived. After ten days most of the messages have been delivered.
We could also show under which conditions the HikerNet operates near the optimum for this type of message transport. Important for the implementation and deployment of the HikerNet we find that a TTL value of 10 is suitable. Due to some implementation issues



(a) Ratio of arrived messages after seven time steps using weighted and random hiker movements.



(b) Ratio of delivery time with respect to optimal delivery time for different hiker movements.

Figure 7: Ratio of arrived messages (a) and delivery time (b) using weighted and random hiker movements.

of the HikerNet prototype we were not able to evaluate the TTR value and the message timeout value.

Simulations also showed that the operation of the HikerNet is not very susceptible to (moderate) changes of the movement pattern. However, the use of stationary nodes seems to improve the performance slightly.

The simulation of the HikerNet is so far only done for sparsely populated areas. For some applications the operation conditions of the HikerNet in more densely populated areas could be interesting. As future work we intend to simulate the HikerNet in a city scenario, where the random meetings between people in the roads have an impact and cannot be neglected like in the mountain-scenario. Additionally the time granularity will be quite different in the city scenario.

The simulation was based on a prototype of HikerNet in order to get results for this specific implementation. Since the performance of the simulation was rather poor in terms of simulation time, we consider to model the entire HikerNet and use an available simulation environment. This could open for simulating properties that cannot be deducted from the current simulation (e.g., the TTR value). This approach would also make the simulation of other scenarios (e.g., the city scenario) more feasible.

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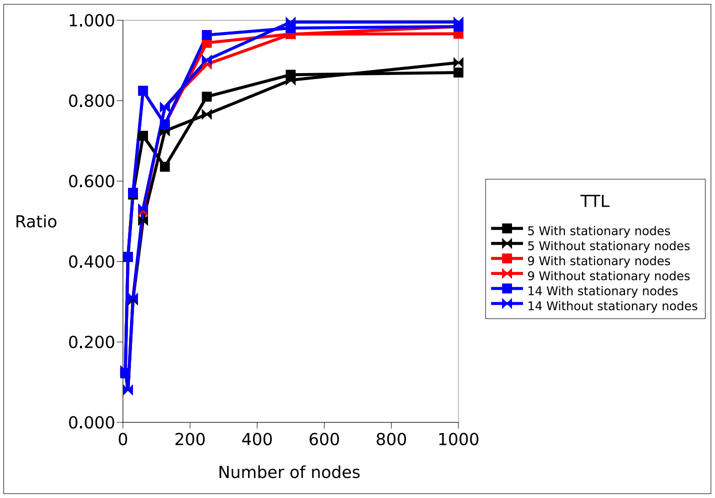

Figure 8: Ratio of arrived messages with and without stationary TN.

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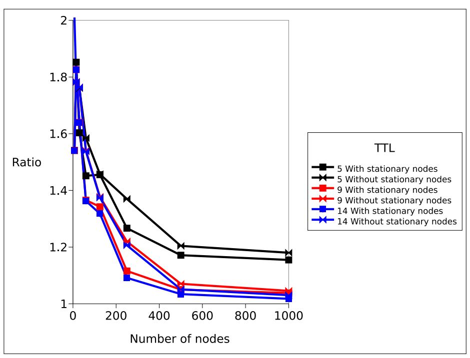
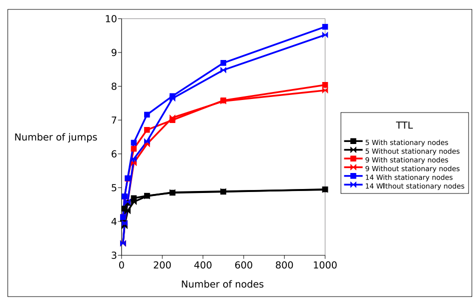


(a) Ratio of delivery time with and without stationary TN.



(b) Ratio of jumps with and without stationary TN.

Figure 9: Ratio of delivery time and jumps with and without stationary TN.