Institut für Technische Informatik und Kommunikationsnetze
Computer Engineering and Networks Laboratory

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Topology Construction in the TOWN Project

Technical Report 271

Ulrich Fiedler, ulrich.fiedler@bfh.ch
Eduard Glatz, eglatz@hsr.ch

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Executive Summary

In this report, we propose and evaluate an algorithm for self-organized topology construction and channel allocation of mesh routers. The routers are equipped with two IEEE 802.16 interfaces. The proposed algorithm is designed to be deployed in a real communication system and specifically addresses a disaster recovery application scenario. Here, the emulation of TDM E1 telephony circuits with worst case provisioning is of primary interest.

The proposed balanced all-greedy algorithm consists of an incremental modified Dijkstra best path algorithm for topology construction which is combined with greedy channel allocation.

To evaluate the algorithm's performance, we have conducted simulations for scenario sizes up to 40 mesh routers among which 4-6 are gateways to the wired network. Using the settings envisioned by Ascom (25mW transmission power, 12 orthogonal channels of 10MHz width in the 5.8 GHz band), and random router placements, we have found that

- The proposed algorithm needs a placement density of at least twelve routers per square kilometer to enable TDM E1 circuit emulation (CE) from routers to gateways.
- The detailed choice of path metrics in the balanced all greedy algorithm has negligible impact on overall network performance for CE.
- Introducing a trade-off between path quality and gateway load significantly improves overall performance. However, the details of adjusting the trade-off have no significant impact on the performance at the scenario sizes investigated.
- Introducing a limited amount of churn to address a semi-static scenario, e.g. such as adding three more routers to the network, or removing one router from the network, does not lead to overall performance degradation.

We currently focus on implementing the proposed algorithm in a VMWare-based test environment to prepare its implementation in ASCOM's demonstrator.

1. Introduction

Wireless mesh networks (WMNs) [1] are multi-hop wireless networks that enable access to a wired network (see fig. 1 for an illustration). WMNs are formed by mesh routers. An interesting field of application for WMNs are in disaster recovery and public safety scenarios in which the use of publicly available networks is either not possible or not appropriate.

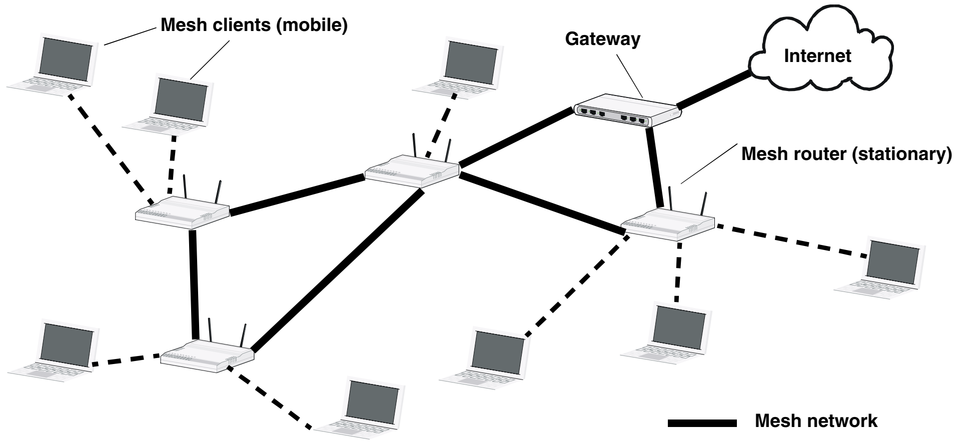

Figure 1: Wireless mesh routers form a **wireless mesh network** (WMN) to enable access to a wired network.

1.1 The TOWN project

In this context, Ascom R&T, TIK/ETH Zurich, and BFH/TI Biel started the **TOWN project** in April 2006. TOWN stands for *telephony over wireless metropolitan area etworks*. The project duration is 23 month. The goal of the project is how to employ upcoming IEEE 802.16-2004 technology (WiMAX) in existing ASCOM equipment to build wireless mesh routers to set up WMNs in disaster recovery and public safety scenarios.

1.2 Technology

Employing **IEEE 802.16-2004 technology** is of particular interest in these scenarios since it widely differs from deployed IEEE 802.11 technology in terms of range, capacity, and quality of service. With 25mW transmission power on omnidirectional antennas, as envisioned by Ascom, the transmission range in the 5.8 GHz band can be up to 1.4 kilometers using an omnidirectional antenna.. Capacities can be up to 30MBit/s. Medium access in IEEE 802.16 is by dynamic time division multiplexing (TDM). This TDM enables quality-of-service guarantees in mesh networks. Moreover, IEEE 802.16, as envisioned by Ascom, has 12 orthogonal channel of 10MHz width compared to 3 orthogonal channels of 22 MHz width in IEEE 802.11b/g.

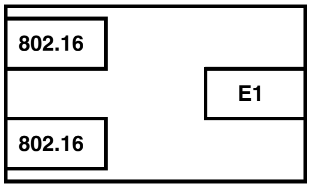

Figure 2: **Ascom's mesh router** is equipped with at least three interfaces. A TDM E1 access interface and two IEEE 802.16 interfaces.

The **IEEE 802.16 interfaces** employed in Ascom's mesh routers were originally designed as last mile technology and can be configured into two modes, subscriber station (SS) mode and base station (BS) mode. In BS mode, the interface opens up a cell and offers connectivity for other mesh routers to connect. In SS mode, the interface can join a cell and connect the mesh router to the network.

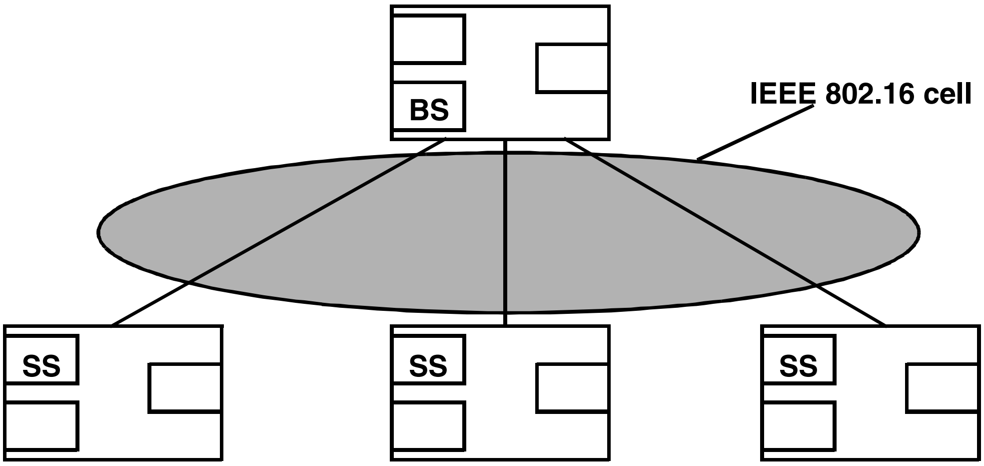

Figure 3: A **IEEE 802.16 cell** that connects four mesh routers. The router on top has one of its interfaces configured to base station (BS) mode. This router opens up a cell and offers connectivity. The routers on the bottom have configured one of their IEEE 802.16 interfaces to subscriber station (SS) mode to join that cell.

1.3 Problem Statement

The TOWN project heads toward building self-configuring mesh routers that automatically form a mesh network once deployed and powered up. As a first step, the project thus studies the **mesh construction problem**. It is well known that wireless interference severely limits network capacity in multi-hop settings [2]. Thus, this report studies how to design algorithms and protocols

(i) That determine how to **construct the network topology**, i.e. (ia) determine which routers need to configure one of its interfaces in base station mode and (ib) which router needs to employ its subscriber station interface to connect to which other router, and
(ii) That determine how to configure or **allocate the available channels** on the base station interfaces

in a way that optimizes the available capacity on the path between the mesh routers and balances the load between the gateways.

1.4 Application scenario

The envisioned **application scenario** in this report comprises around 40 wireless mesh routers dispersed over a metropolitan area of about $10km^2$. Around 10% of these routers are gateways that connect the wireless mesh network to an infrastructure network.

Within this application scenario, we distinguish between a “static”, a “semi-static”, and a “dynamic” scenario. The **static scenario** describes the situation where all mesh routers forming the network have been placed and physical conditions (weather, etc.) are stable. This scenario is on hand when rescue forces are on site for several hours. The scenario is, by definition, characterized by little or no churn, i.e. very few or no mesh routers join or leave the network. The **semi-static scenario** describes the situation where mesh routers are currently deployed. This scenario is reached when rescue forces arrive on site. This scenario is, by definition, characterized by significant churn, mesh routers join or leave the network in a rate of several minutes. The **fully dynamic scenario** describes the situation where mesh routers join and leave the network at rates smaller than a minute. Such scenarios are relevant in battlefield support. However, this report focuses on the static and semi-static scenario.

The **traffic in the application scenario** is packet circuit-switched telephony traffic which has stringent quality of service requirements. The network is to be provisioned for the worst case. The underlying reason is that supporting telephony is key in the disaster recovery and public safety scenarios. The worst case traffic volume is 2MBit/s from each mesh router up to the gateway and 2MBit/s from the gateway down to the mesh router. This volume follows from the fact that Ascom’s mesh router implement a TDM E1 interface for circuit-switched traffic.

1.5 Our Approach

Our approach to the mesh construction problem is inspired by a divide and conquer strategy to reduce the complexity. In this report we thus review topology construction and channel allocation before we come up with the integrated balanced all-greedy algorithm that can be employed for simultaneous distributed topology construction and channel allocation. The overall concept of the algorithm is as follows:

(i) Elect or configure one of the gateways in the scenario as a master gateway.
(ii) Start at this master gateway and subsequently invite the routers (including other gateways) to join and build the mesh network.
(iii) To determine which router to join next, we propose to measure SNRs on all potential links that could be chosen in the topology construction and map these measurements to link qualities.
(iv) Based on the link qualities, we infer path qualities to the gateways and incrementally decide which router to join next to build the network.
(v) If this join requires switching on a base station interface, we allocate a channel and switch this interface on.

We justify this approach with a review of graph theory, evaluate the approach with QualNet simulations and show how to implement it in Ascom's routers for use in both a static and a semi-static scenario.

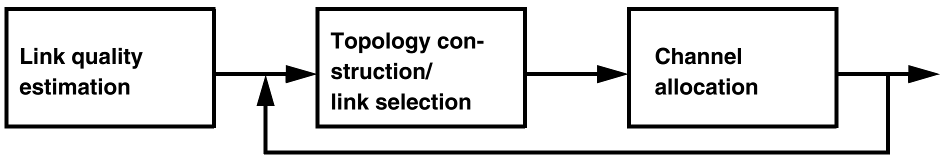

Figure 4: Our approach for mesh construction is incremental and involves link quality estimation, link selection and channel allocation.

The rest of the report is structured as follows:
Section 2 reviews link quality estimation. Section 3 reviews topology construction. Section 4 reviews channel allocation. Section 5 describes the balanced all-greedy algorithm that we propose. Section 6 discusses evaluation results. Section 7 reviews implementation issues. Section 8 concludes with a discussion.

2. Link quality estimation

Before establishing a link, we propose to estimate the link quality from **SNR measurements.** It is known fact that the minimal receiver SNR determines modulation and coding scheme on the links and thus this link's capacity. The values for this relation are listed in table 1. This capacity can now be used to infer the **link quality estimates** when selecting links to construct the mesh network topology. The SNR values can be derived from MAC layer SNR measurements.

Minimal Receiver SNR [dB]	**Modulation and coding scheme**	**Capacity [Mbps]**
6.0 9.0	QPSK 1/2 QPSK 3/4	5.7 8.5
11.5 15.0	16QAM 1/2 16QAM 3/4	11.3 17.0
19.0 21.0	64QAM 2/3 64QAM 3/4	22.7 25.5

Table 1: Relation between SNR, modulation and coding scheme and link capacity on layer 2. The SNR values shown are the ones that are implemented in the Qualnet 4.0 simulator. The MAC layer capacities are derived from the physical layer capacities assuming a 25% overhead, a bandwidth of 10 MHz and a cyclic prefix (CP) value of 1/16.

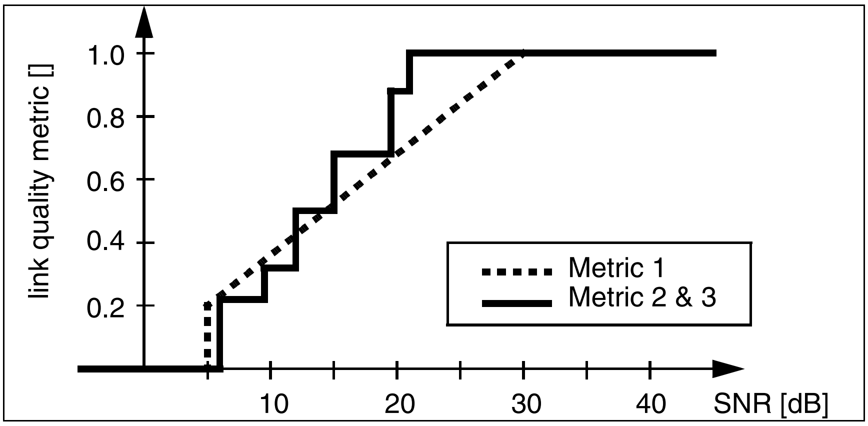

Figure 5: The choice of modulation and coding schemes based on minimal receiver SNR can be employed to infer link quality estimates between 0 and 1. 0 stands for no capacity and 1 stands for maximal capacity.

3. Topology construction

By definition, the topology construction problem is the problem to select an interconnected set of backbone routers that need to switch on their base station interfaces to connect all routers to the gateways in a way that maximizes capacity in the network. This problem can be mapped to a **connected dominating set problem**[1] in graph theory. We review and adopt the solutions to this problem.

In this mapping from topology construction to a connected dominating set problem, mesh routers correspond to vertices in a graph; potential links correspond to the edges; the link qualities correspond to weights on the edges. Selecting backbone routers, that need to switch on their base station interfaces to offer connectivity, can be mapped to computing a connected dominating set of vertices in this graph (see figure 6 for an example). Maximizing capacity between routers in the network can be mapped to maximizing path qualities in a graph.

Hence, computing the connected dominating set can be achieved with a modified shortest path Dijkstra algorithm comparable to the algorithm employed in **Open Shortest Path First (OSPF) routing**.

3.1 One gateway case

Conceptually, we think of the graph and a wave front that separates vertices that are already contribute to the network from vertices that do not contribute yet. The wave front starts at the vertex that represents the gateway and flushes through the graph. Vertices subsequently join one after another as the wave front proceeds. The sequence of joins is given by the path quality which can be inferred from the weights on the edges of the graph that represent the link qualities.

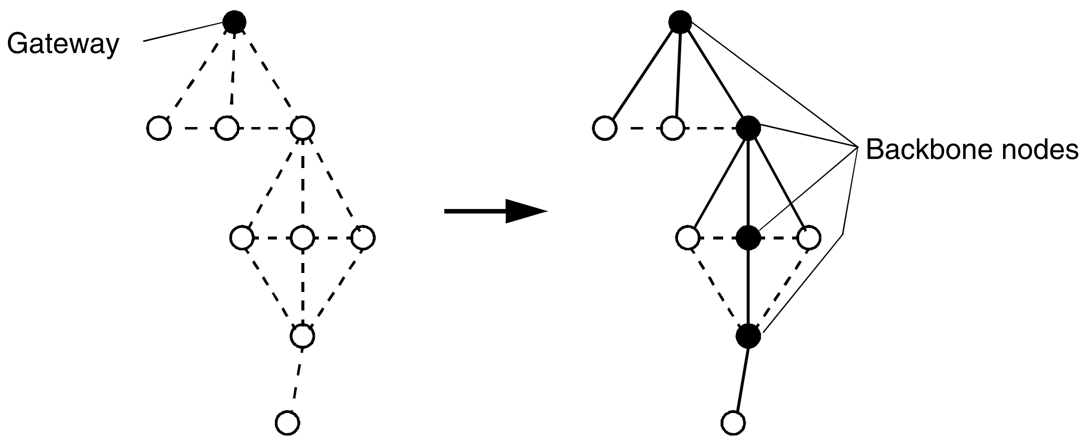

Figure 6: Example for the mapping of a topology construction problem to a connected dominating set problem in graph theory. Selecting an interconnected set of backbone routers (yellow) that need to switch on their base station interfaces can be mapped to computing a connected dominating set in a graph.

Joining vertices need a parent vertex behind the wave front. Upon join, the parent vertex becomes member of the connected dominating set if it has not been in this set already. The parent thus corresponds to a backbone router. The edge to the

[1] In graph theory, a graph consists of vertices and edges. A connected dominating set of a graph consists of the vertices of a dominating set of the graph plus a number of vertices that are needed to interconnect the vertices in the dominating set. A dominating set is a subset of the graph's vertices that has all remaining vertices adjacent to at least one vertex in the set.

parent corresponds to a backbone link in the network (see figure 6 for an illustration). Thus, the modified Dijkstra shortest path algorithm can be employed to select backbone routers and to identify backbone links.

Moreover, the similarity of this algorithm to the one employed in OSPF suggests that this algorithm is **easy to distribute** (see section 7 on further details).

3.2 Multiple gateways

Multiple gateways can be handled by the algorithm by selecting one **master gateway** and modeling the wired connection between the gateways as a link with optimal capacity/quality. Then the wave front starts at the vertex that represents the master gateway, proceeds to vertices that represent gateways before continuing to vertices that represent ordinary routers.

3.3 Load balancing between gateways

The fact that traffic concentrates at the gateways and that a particular gateway may get overloaded needs to be addressed. To address this fact, we propose to employ a composite path metric when determining the topology with the modified Dijkstra algorithm. This composite path metric balances between the path capacity or quality and the traffic load already present on each gateway.

The formula for the composite path metric is given by

Composite path metric = w * (path quality) + (1-w) * (traffic load), $0 \leq w \leq 1$.

W=0 means a total focus on load balancing, and w=1 means to total focus on path qualities.

A simple formula for the traffic load part of the metric (tlm) is given by

tlm = (GWcapacity – numAlreadyAssignedNodes) / GWcapacity.

We further elaborate on load balancing and choosing metrics when evaluating the algorithm.

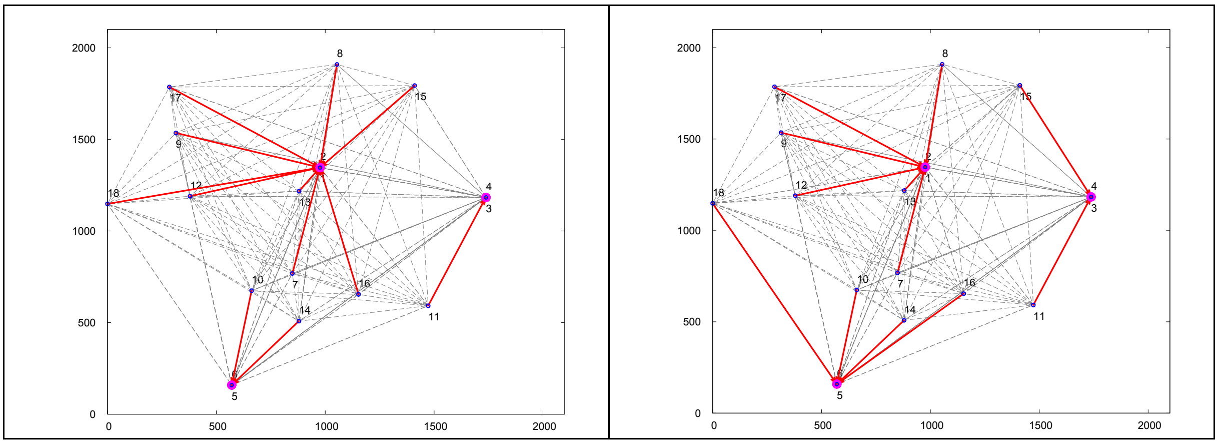

Figure 7: Illustration of the effect of balancing load between gateways. The red lines mark topology links and the thin dashed lines show potential connectivity.
Left: No load balancing results in overloading of the gateway in the center. Right: Minimally accounting for gateway load during topology construction when computing the composite path metric leads to a more balanced topology (w=0.8).

4. Channel allocation

The next step after identifying the backbone routers that are required to build the network topology is to assign channels to the cells made up by the base station (BS) interfaces of those routers. The assignment of the channels to BS interfaces/cells has to be done in a way that minimizes loss of network capacity due to interfering among cells.

The problem of assigning the k available channels to the cells can be mapped to a known graph coloring problem, namely to computing a **max-k-cut to an interference graph**.

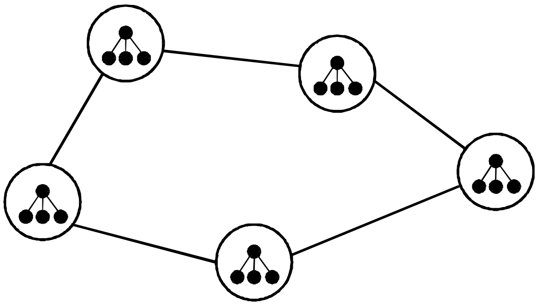

Figure 8: Interference conflict graph. Each vertex in the graph represents a WiMAX cell in the network topology. Each edge represents a potential interference conflict between the vertices at its ends. This conflict arises when the cells represented by the vertices at both ends are put to the same channel.

In this **interference graph** each vertex represents a IEEE 802.16 (WiMAX) cell in the network topology. The color of the vertex represents the channel assignment to this cell. Each edge represents a potential interference conflict between assignments. The conflict arises when the cells represented by vertices at the two ends of the edge are assigned to the same channel. The conflict diminishes when the channel assignments differ. Thus, the problem of finding an optimal channel assignment with k available channels can be mapped to the problem of coloring this conflict graph with k colors in a way that maximizes the number of conflict edges that have vertices with different colors at both ends. This problem is known as the max-k-cut problem [3].

The **max-k-cut** problem is known to be NP-hard [3]. It may thus not be feasible to compute the optimal solution. However, there is a number of approximation algorithms that show good performance in both average and worst case [3]. These approximation algorithms include greedy, merge, genetic, and tabu-search.

Presumably, the choice of the approximation algorithm has not a major impact on network capacity since we have 12 channels in a network of 40 mesh routers or smaller. We thus focus on the **greedy algorithm**, that assigns the k available channels in a round-robin manner (see fig. 9 for an illustration), and present a way to combine the greedy algorithm with incremental topology construction that can be implemented in wireless mesh routers.

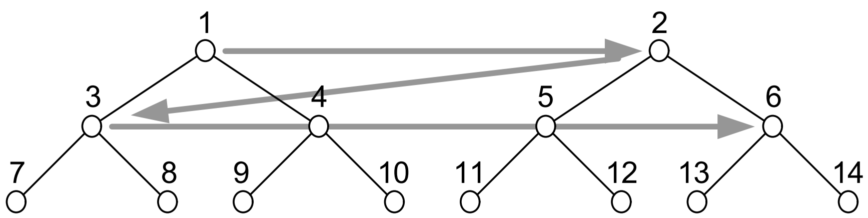

Figure 9: Greedy channel assignment for base station interfaces of backbone routers following the order in which routers have joined the network.

5. The balanced all-greedy algorithm

For the static scenario we can now state the all-greedy algorithm for mesh construction by adding **greedy channel allocation** to the **modified Dijkstra algorithm** of section 3. This allows us to incrementally join routers to the net starting at the master gateway.

We call this algorithm **balanced all-greedy** because it is greedy with regards to (i) topology construction, where it maximizes path capacities, and to (ii) channel allocation, where it minimizes loss of capacities due to interference. The attribute balanced comes from the possibility to trade off path capacity vs. gateway load to minimize gateway overload when constructing the topology.

We assume that each router keeps a **topology database** and subsequently runs the algorithm on this database after each join. The database is employed to keep track of

- (i) All links and routers forming the network topology.
- (ii) All channel assignments on BS interfaces of these routers.
- (iii) Minimal SNR measurements on all routers.

To construct the network and to populate the topology database, we essentially need **three types of messages**: join requests, invites, and topology changes. Then we can start at the master gateway and send out a “wave front”. This wave front separates "the net" from "the unkown" and drives the incremental mesh construction.

Constructing the topology then goes as follows:
Routers adjacent but outside the wave front are join candidates that send join requests on all channels on which they sense activity. If no activity is sensed, a default management channel is used. Routers adjacent but inside the wavefront measure the SNRs of these join requests, infer potential link qualities and run the modified Dijkstra algorithm on their local topology database to determine which router issues the next invite to a join candidate. This router then configures its base station interface with the greedy algorithm, unless this interface has not been configured before, and sends an invite message to the join candidate. The join candidate can now join the network and send a topology change. This topology change includes SNR measurements of join requests it has received from further join candidates. The topology change is then flooded throughout the network. When all routers have received the topology change, the modified Dijkstra algorithm is employed on the topology database to determine which router can issue the next invite.

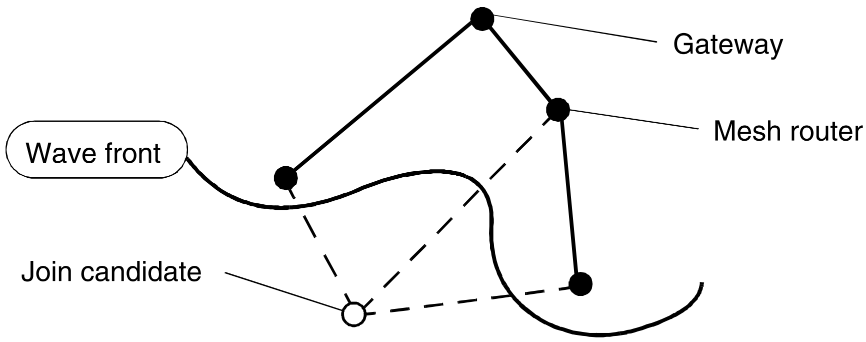

Figure 10: Illustration of a join. The black circles mark routers which are part of the network and are hence behind the wave front. The white circle marks a router which is a join candidate, i.e, could be connected to the network along one of the dashed links. The modified Dijkstra algorithm then selects the candidate with the best path and the link that is associated with the best path. This candidate joins next and the wave front is advanced.

For implementation details refer to section 7.

6. Evaluation

We have implemented the proposed balanced all greedy topology construction and channel allocation algorithm and have conducted network simulations with QualNet to evaluate its performance.

6.1 Simulation settings

The IEEE 802.16 interfaces of the wireless mesh routers are configured to one of 12 orthogonal channels which work at 5.8 GHz and have a bandwidth of 10 MHz. Transmit power is set to 25mW. Antennas are omnidirectional and have a height of 5 m. Routers are placed randomly over an area of 1400m x 1400m, 2100m x 2100m or 2800m x 2800m in a way that each router has at least one peer router in its connectivity range. Circuit-switched traffic is simulated as a pair of 2 Mbps constant bit rate (CBR) streams between each mesh router and a gateway. We run the simulation for 100s. We repeat each run twenty times with different randomly generated router placements.

6.2 Coverage

Reviewing our simulations, we have found that the special **router placement density** in the scenario has to be above 12 per square kilometer (see figure 11). This density is necessary to ensure a packet delivery ratio that is so close to one that circuit emulation traffic can be supported. Partically, this density is only achieved in the 1400m x 1400m scenario size. We thus focus the rest of our evaluation on this scenario size.

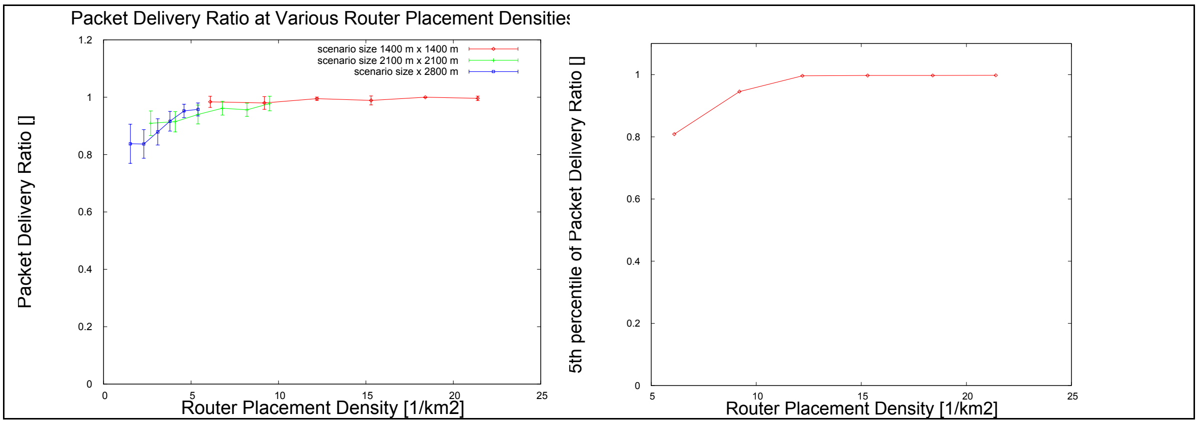

Figure 11: Packet delivery rate at various router placement densities. The figure on the left side shows the simulation results for the three different scenario sizes.The figure on the right shows the minimum packet delivery rate obtained on 95% of the links. A reasonable PDR can only be achieved when more than 12 routers are placed per square kilometer.

6.3 Selecting path metrics

Next we assess the sensitivity of the all greedy algorithm on the choice of path and link quality metrics. We consider the following metrics.

Metric no.	Link quality	Path Quality
1	(1) ramp function in fig. 5	Product of link qualities
2	(2) step function in fig. 5	Minimum of link qualities
3	(2) step function in fig. 5	Product of link qualities

Table 2: Definition of metric types by their assignment to link quality and path quality formulas.

We note that the reasoning behind employing the product to derive the path quality from the link qualities on the path is that packet delivery ratios are multiplicative under the assumption of independence of packet loss.The reasoning behind employing the minimum is simply that the path capacity is determined by the capacity on the bottleneck link.

However, our simulation results show that the details of the path metric have little impact on the packet delivery ratio (see fig 12). In terms of SNR, metric 2 and 3 outperform metric 1 (see fig 12). This finding can be explained with the fact that a ramp function is an inaccurate approximation to model the SNR to link capacity relationship. Moreover, we note that in the scenario studied, packet delay is always smaller than 2ms and packet jitter is smaller < 5ms which is acceptable for circuit emulation. (For further details of the evaluation refer to appendix 10.x).

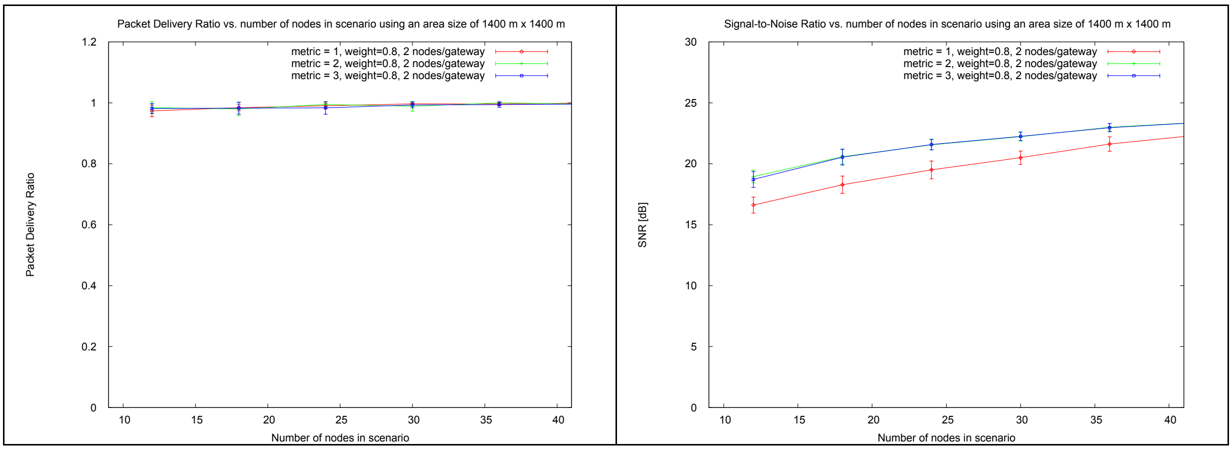

Figure 12: Packet delivery ratio and SNR of the all greedy algorithm with three different path quality metrics. The figure on the right shows that metrics 2 and 3 always leads to better average SNRs compared to metric 3. However, this better SNR does not necessarily lead to a better packet delivery ratio.

6.4 Trade off between path quality and gateway load

Next, we investigate the trade off between path quality and gateway load. Fig 13 shows that accounting for gateway load significantly improves the packet delivery ratio. However, the details of the choice of the trade-off parameter w in formula xx is not significant. Packet delivery ratio and SNR are best with w=0.7 for the scenario sizes we investigated. However, the improvement over w=0.6 and w=0.8 is insignificant.

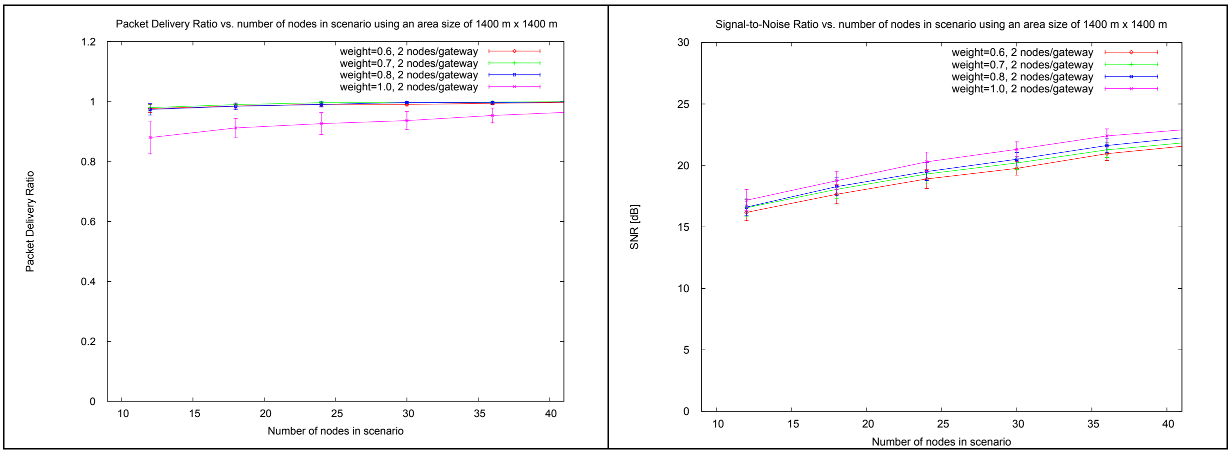

Figure 13: Trading path quality versus gateway load increases the packet delivery rate.

6.5 Churn (joins and leaves of mesh routers)

Finally, we investigate the performance of the algorithm in a semi-static scenario. We consider three cases:

- 3 mesh routers join the network all at a time
- 3 mesh routers subsequently join the network
- one mesh router leaves the network

Comparing the resulting packet delivery ratio and SNR to the original values, we find that this amount of churn has no impact on the packet delivery ratio (see figure 14). We explain this finding by the fact that the number of backbone routers is small for the chosen scenario size and thus it is unlikely that a joining node is part of the backbone.

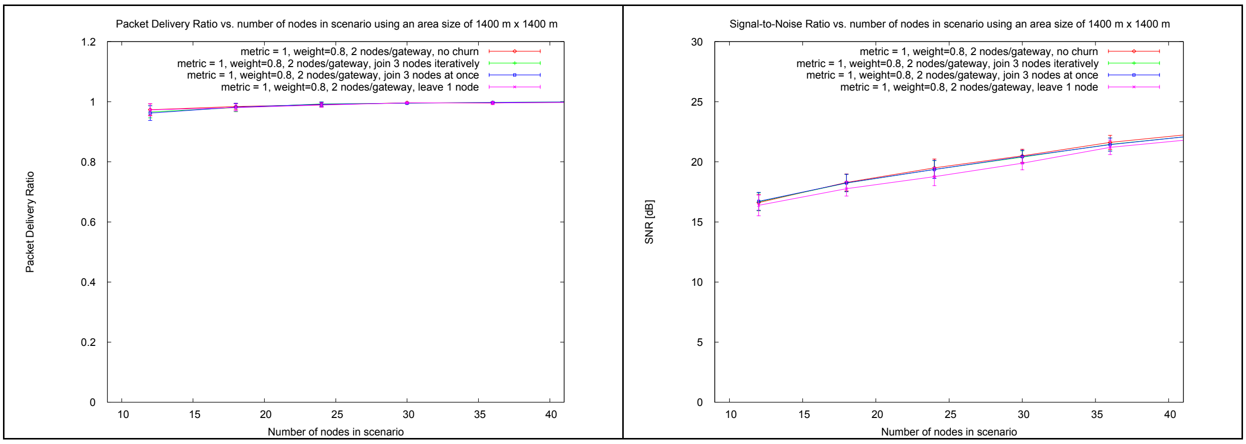

Figure 14: Evaluation of performance when mesh routers join and leave. The results show that joins and leaves do not degrade performance in general.

7. Implementation

We propose to implement the algorithm in a WMWare-based test environment before porting it into ASCOM’s demonstrator. In this test environment, each router is emulated by a separate process. These processes use protocol messages and communicate through sockets just like in a real network. This proposition has the advantage to separate algorithm and protocol verification from demonstrator hardware validation. The test environment is already set up at BFH Biel. We are currently porting the algorithm.

8. Discussion and further work

In this report, we have proposed and evaluated an algorithm for a self-organizing topology construction and channel allocation in mesh routers that are equipped with two IEEE 802.16 interfaces. We have specifically focused on the application scenario disaster recovery where the emulation of TDM E1 telephony circuits with worst case provisioning is of primary interest.

The proposed balanced all-greedy algorithm consists of an incremental modified Dijkstra best path algorithm for topology construction which is combined with greedy channel allocation.

To evaluate the algorithm's performance, we have conducted simulations for scenario sizes up to 40 mesh routers among which 4-6 are gateways to the wired network. Using the settings envisioned by Ascom (25mW transmission power, 12 orthogonal channels of 10MHz width in the 5.8 GHz band), we have found with random router placements that

- the proposed algorithm needs a placement density of at least twelve routers per square kilometer to enable TDM E1 circuit emulation (CE) from routers to gateways.
- The detailed choice of path metrics in the balanced all greedy algorithm has negligible impact on overall network performance for CE.
- Introducing a trade-off between path quality and gateway load significantly improves overall performance. However, the details of adjusting the trade-off have no significant impact on the performance at the scenario sizes investigated.
- Introducing a limited amount of churn to address a semi-static scenario, e.g. such as adding three more routers to the network, or removing one router from the network, does not lead to overall performance degradation.

We currently focus on implementing our algorithm in a VMWare-based test environment to prepare its implementation in ASCOM's demonstrator.

Morever, we'd like to stress that we still have lots of open issues such as

- How is the algorithm behaving in more dynamic environments with more churn?
- How is the algorithm behaving when SNRs significantly change e.g. due to sudden change of weather conditions?

9. References

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10. Appendix

10.1 Simulation Results

10.1.1 Selecting path quality metrics

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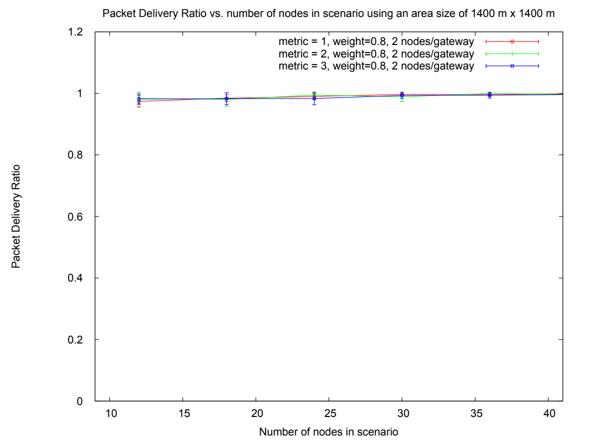
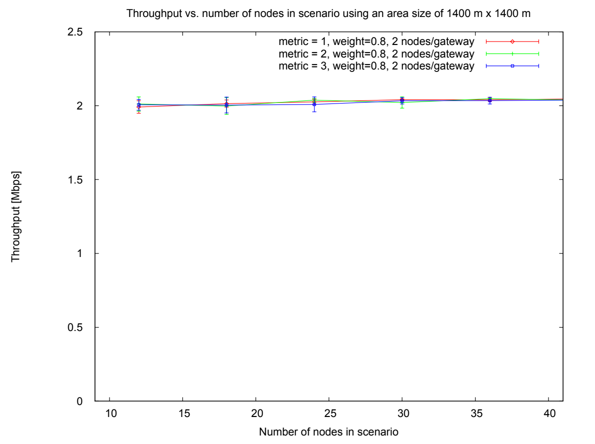
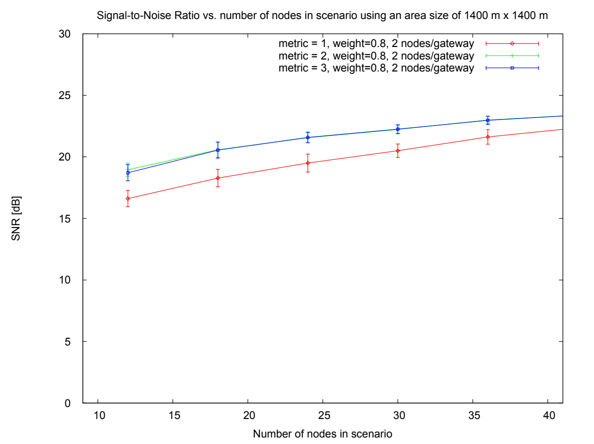
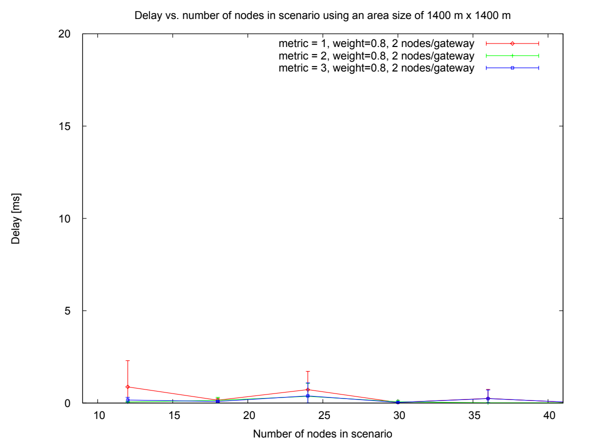
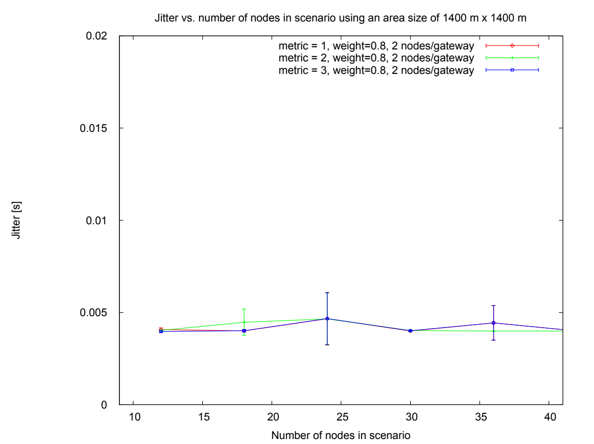


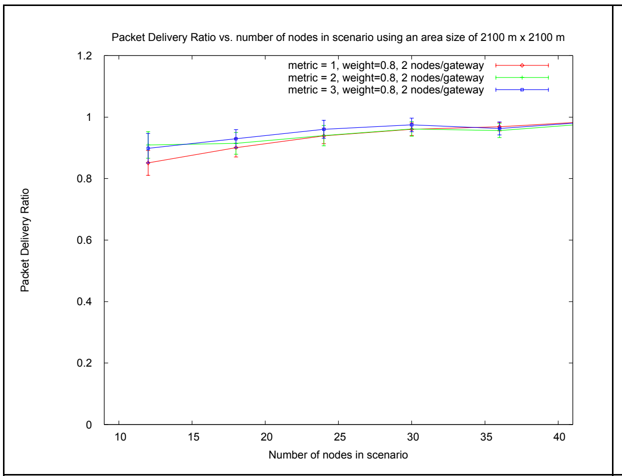


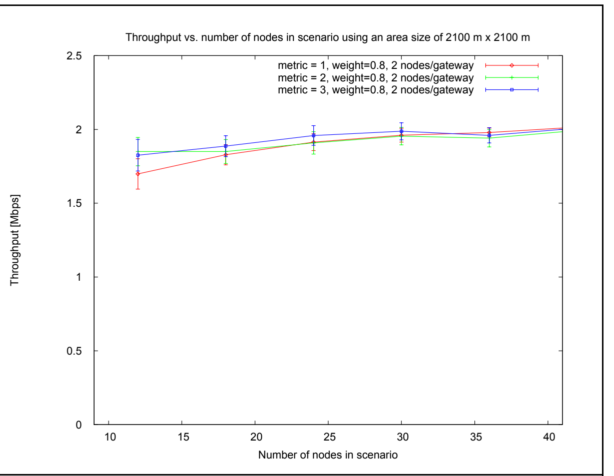


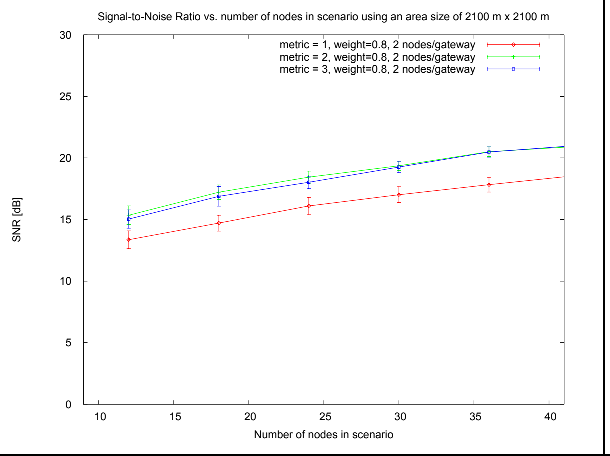


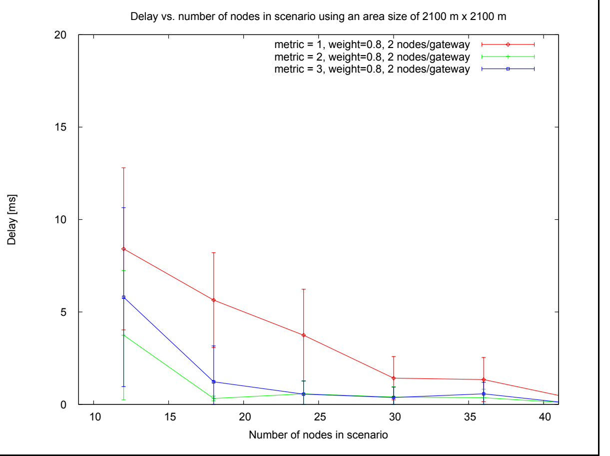


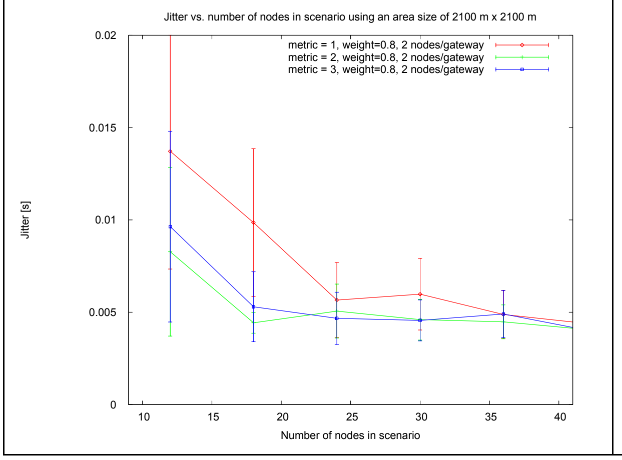
scenario size 2100 m x 2100 m:



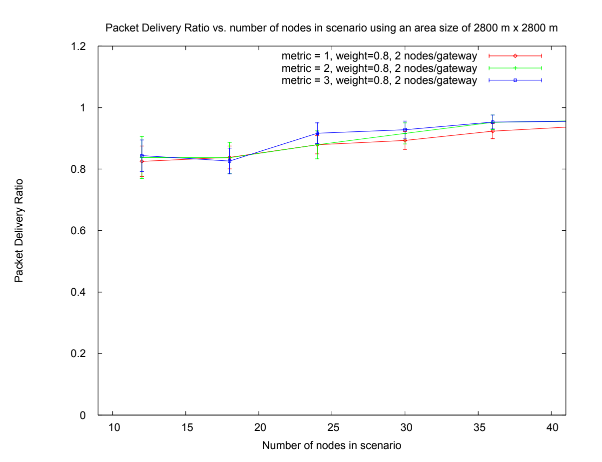


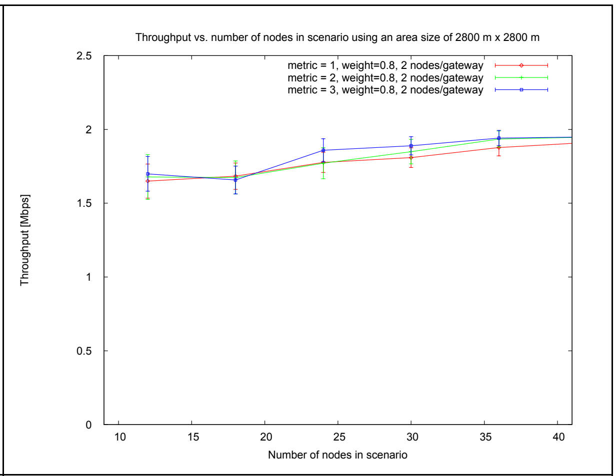


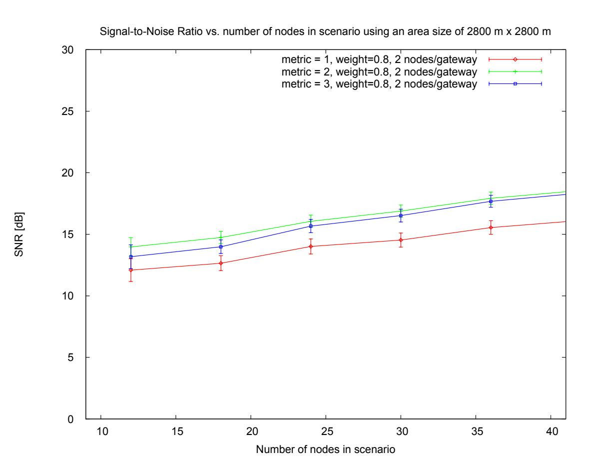


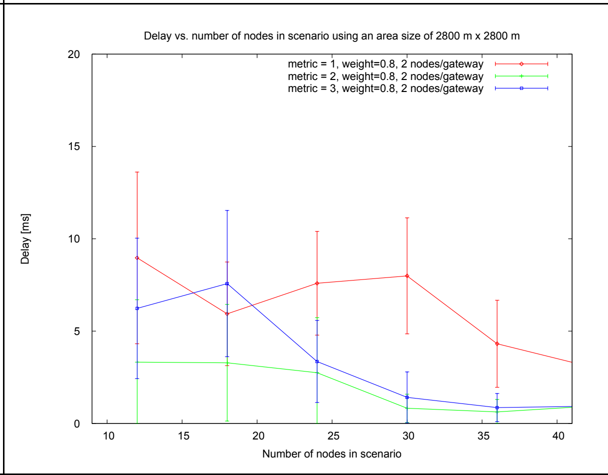


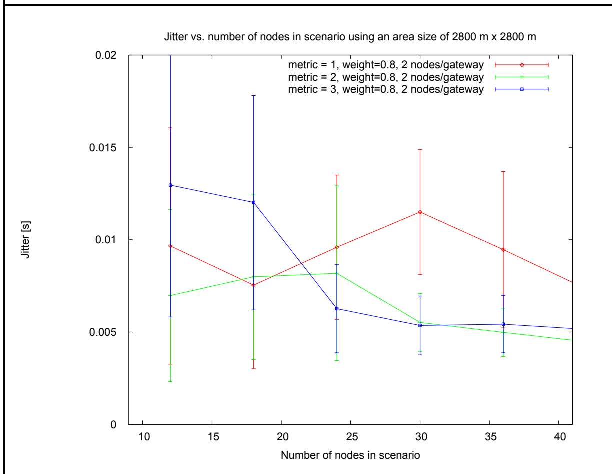
scenario size 2800 m x 2800 m:





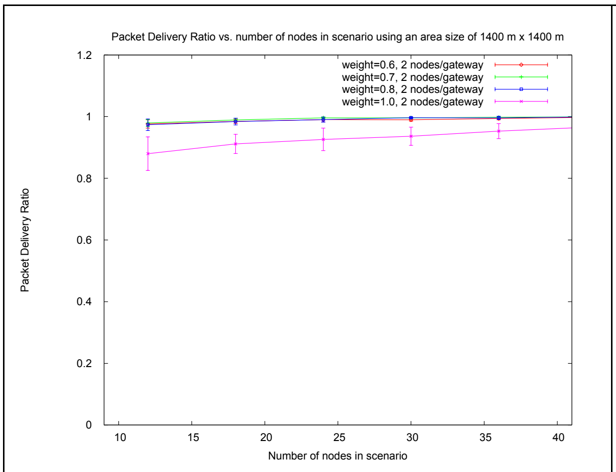


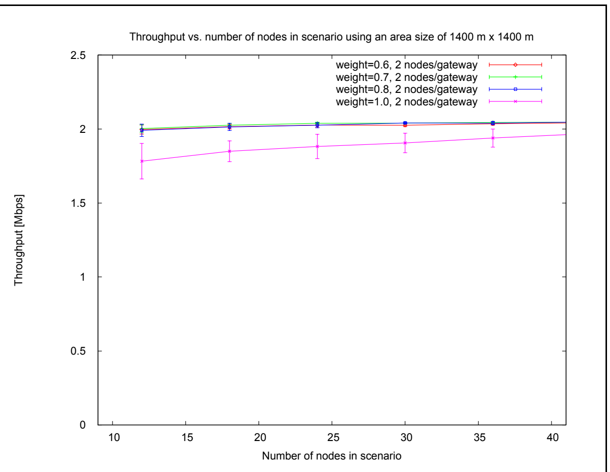


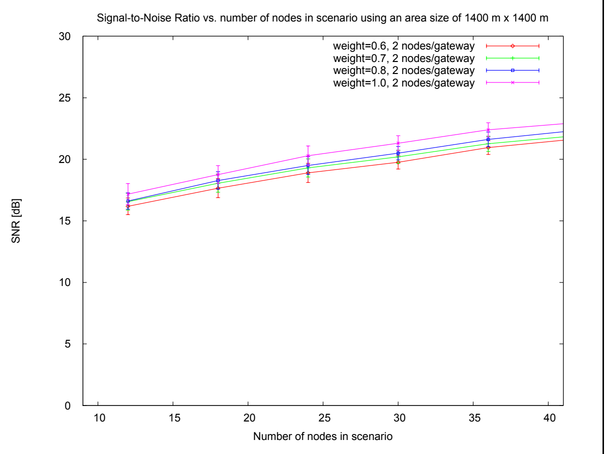


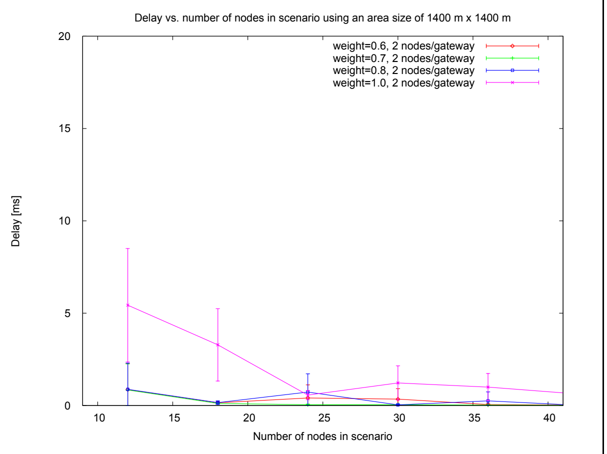
10.1.2 Trade-off between path quality and load balancing

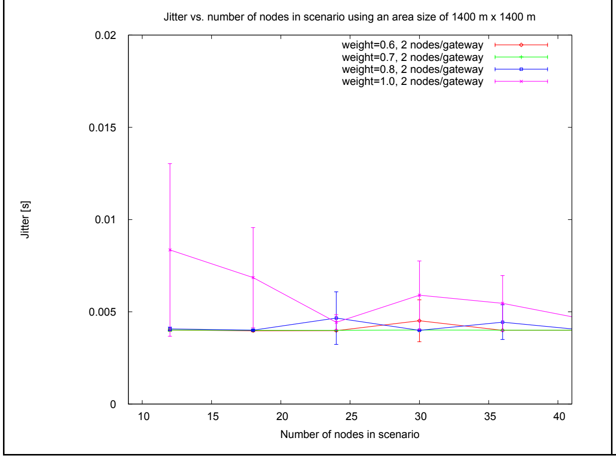
Scenario size 1400 m x 1400 m:



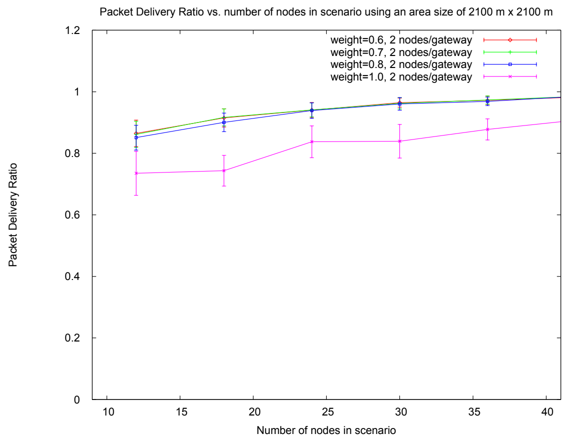


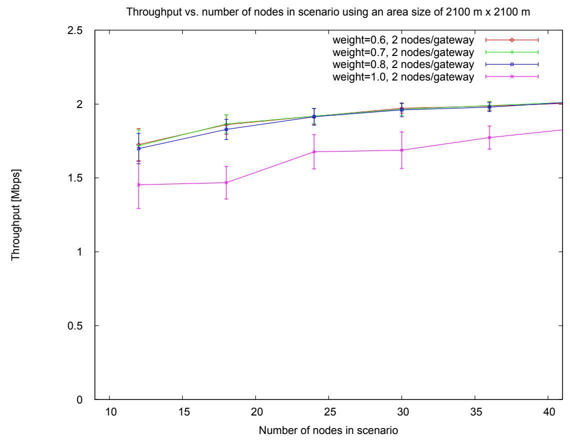


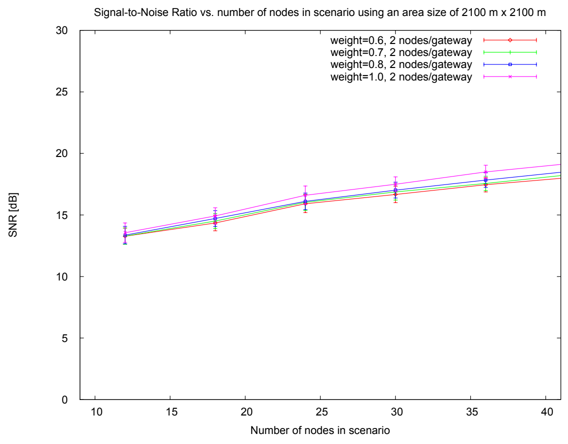


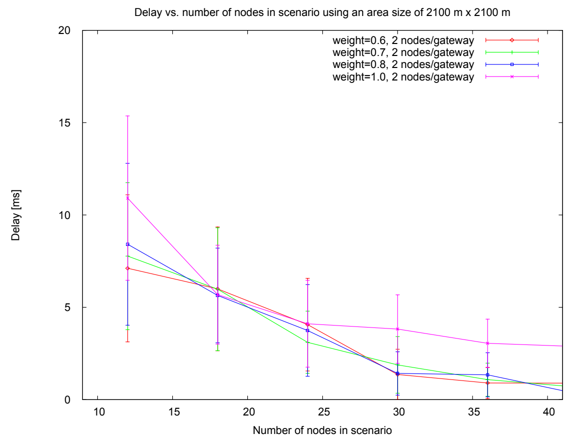


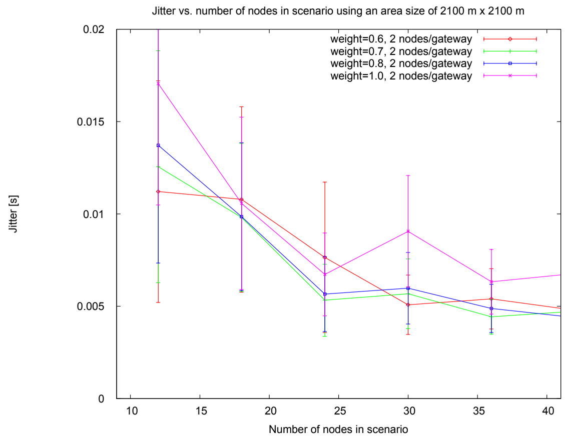
scenario size 2100 m x 2100 m:



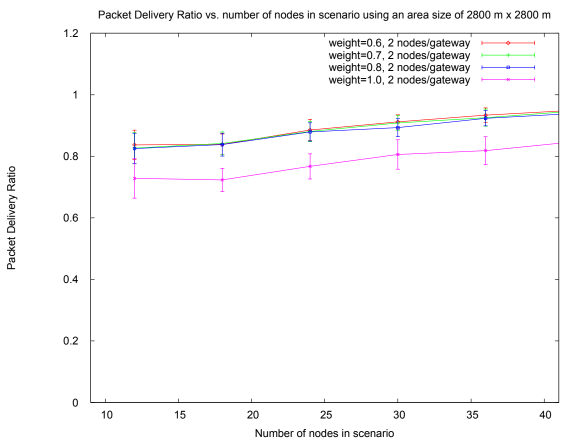


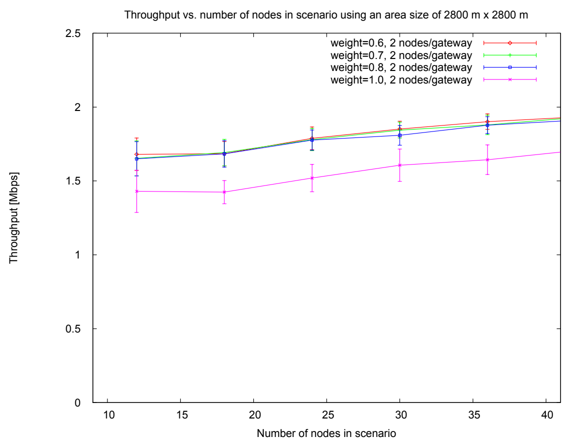


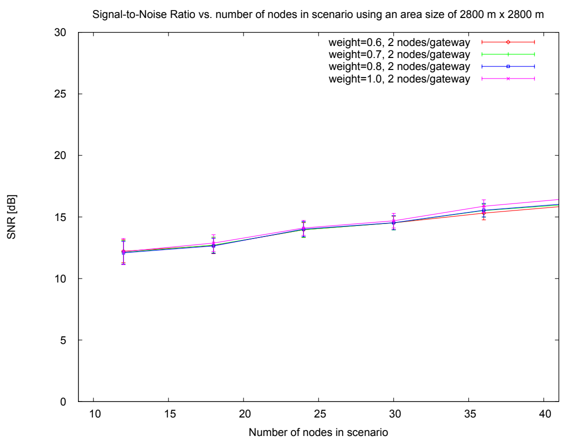


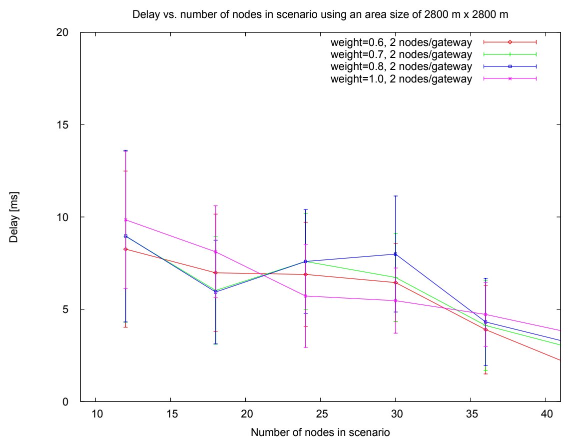


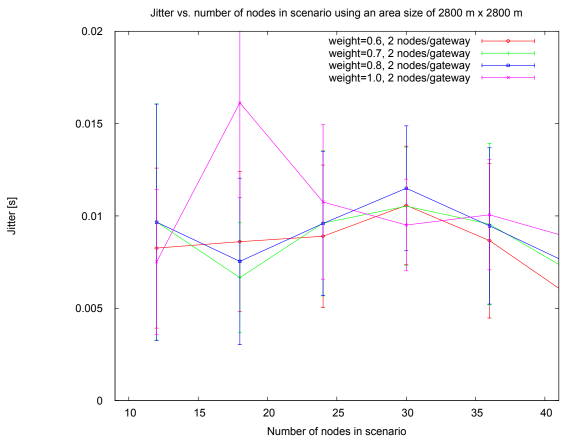
scenario size 2800 m x 2800 m:





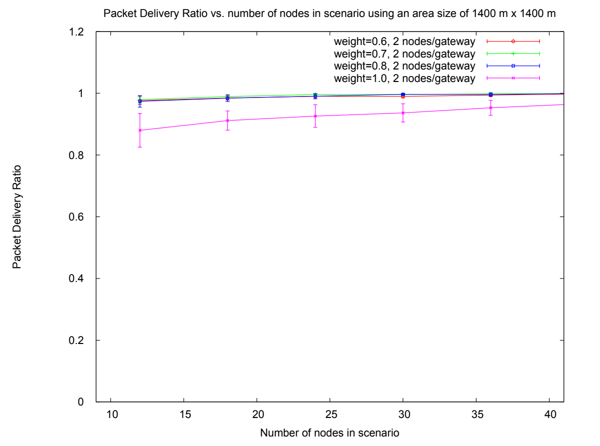


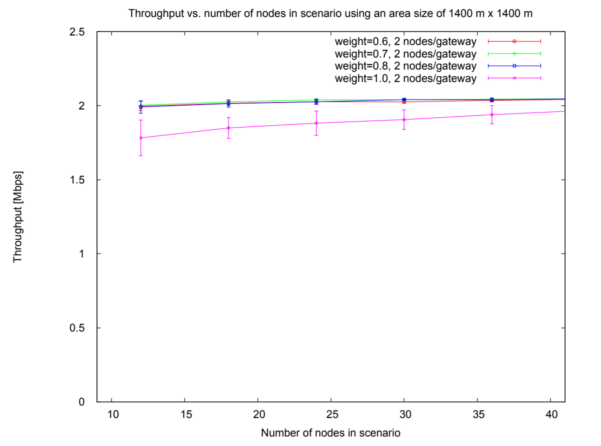


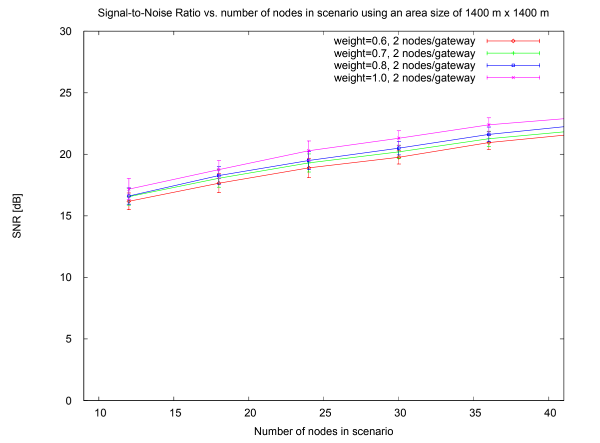


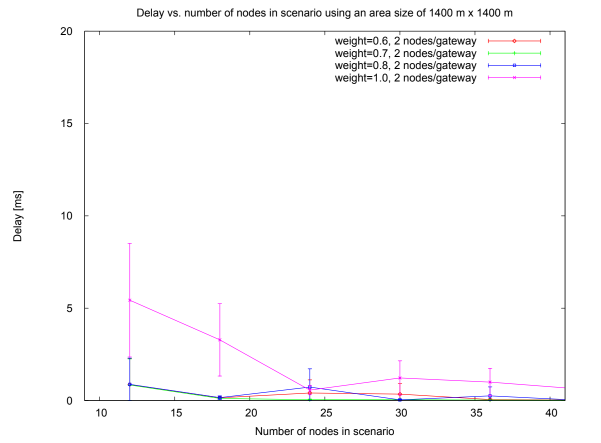
10.1.3 Trade-off between path quality and load balancing

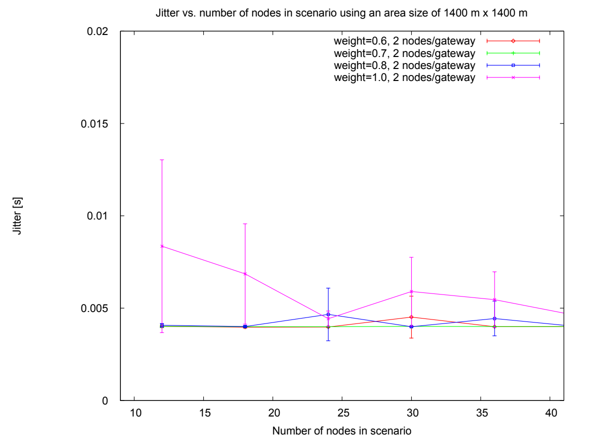
Scenario size 1400 m x 1400 m:



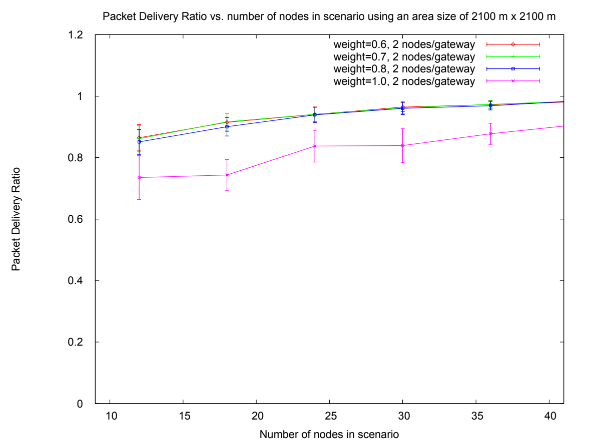


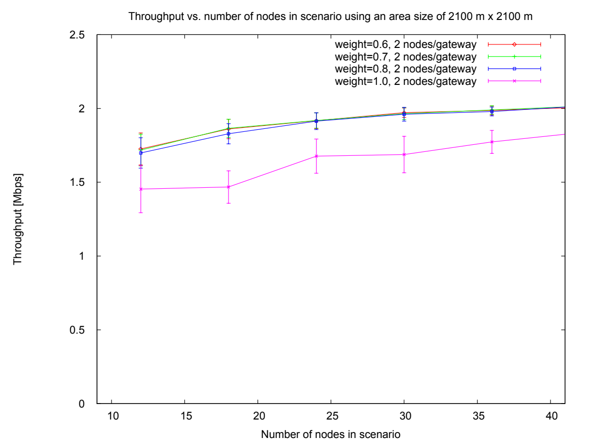


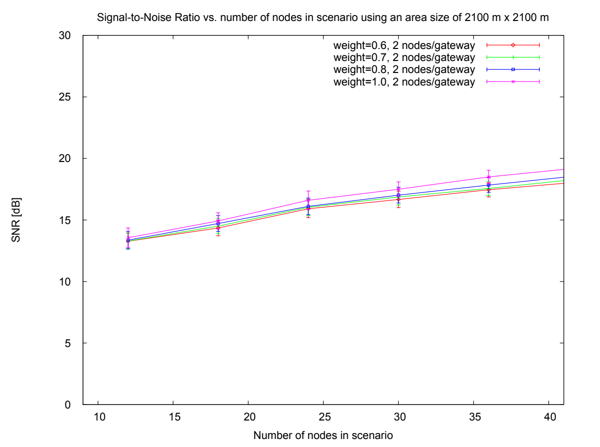


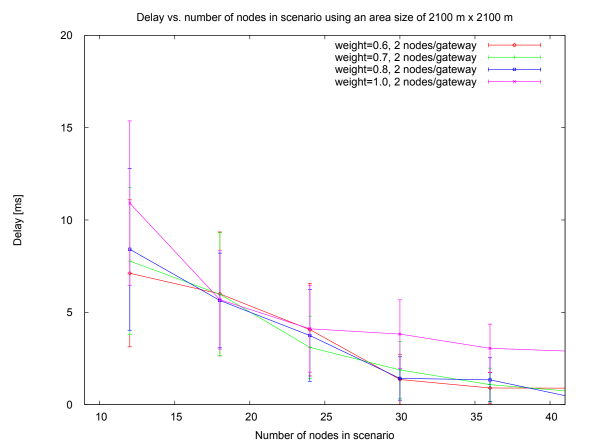


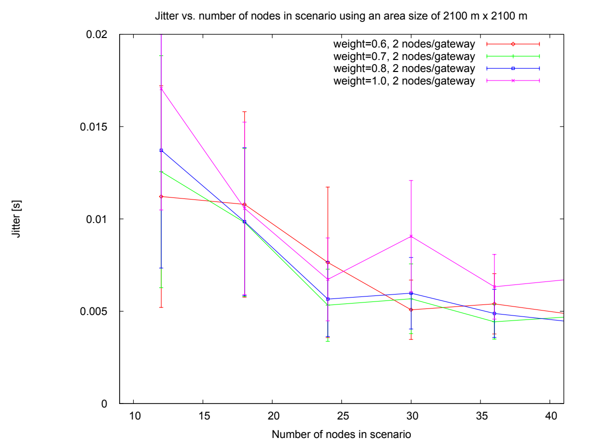
Scenario size 2100 m x 2100 m:



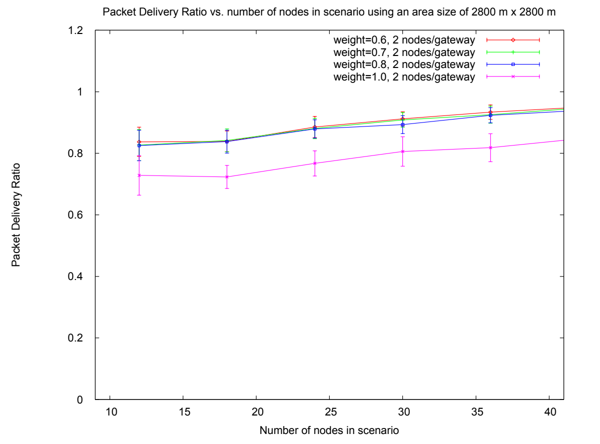


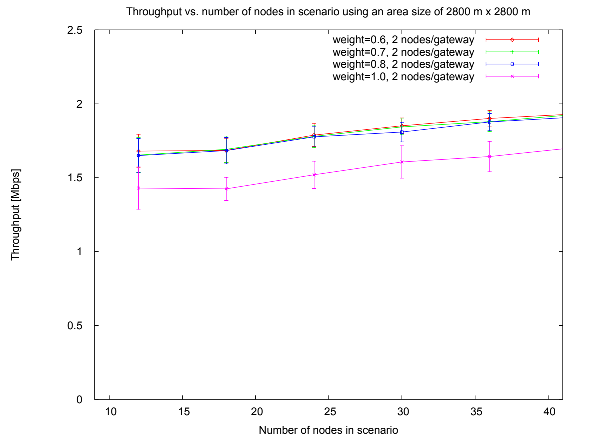


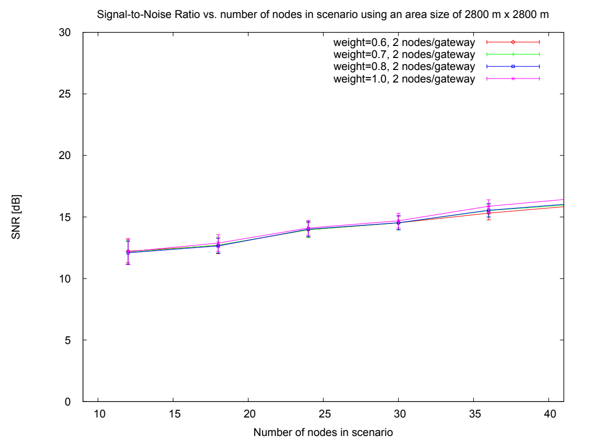


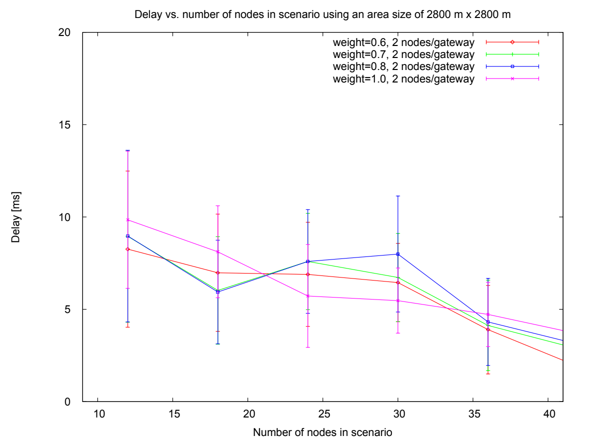


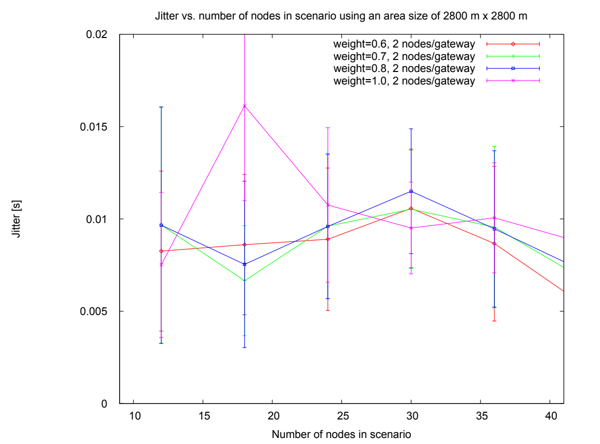
Scenario size 2800 m x 2800 m:





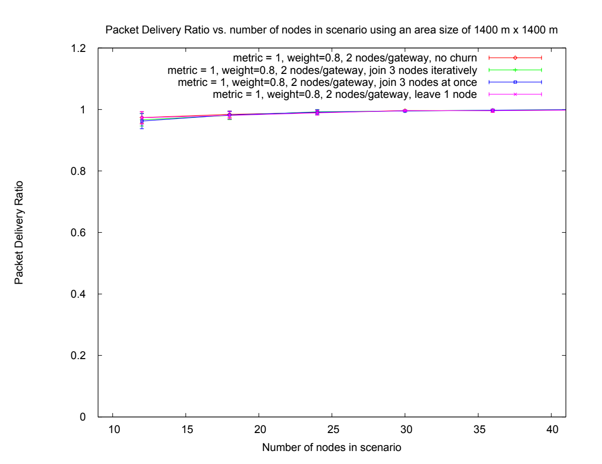


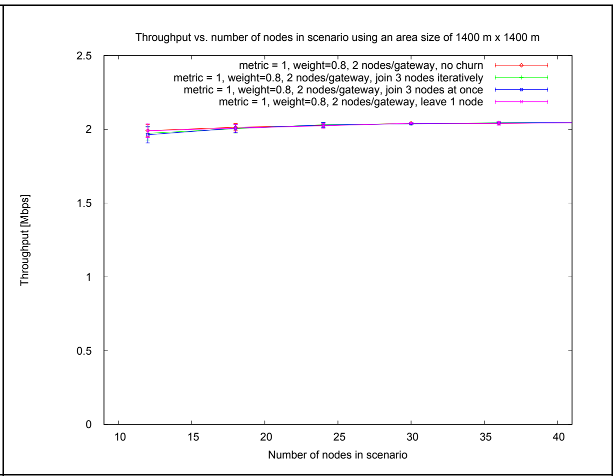


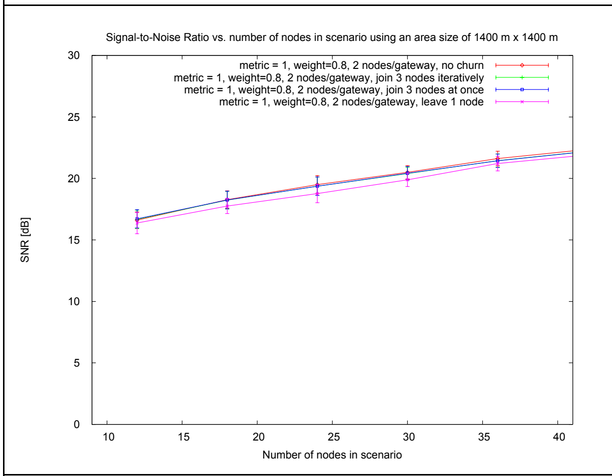


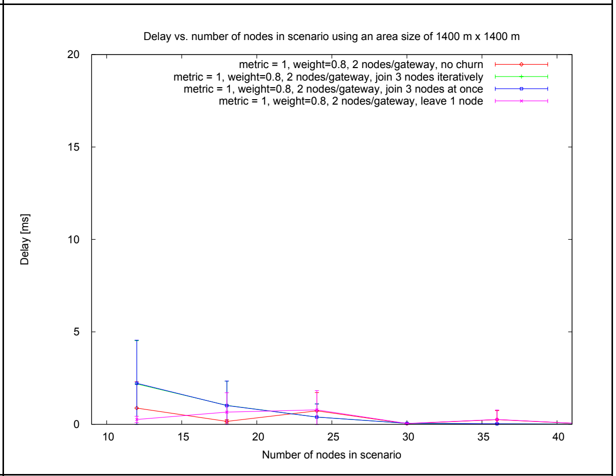
10.1.4 Churn (joining and leaving mesh routers)

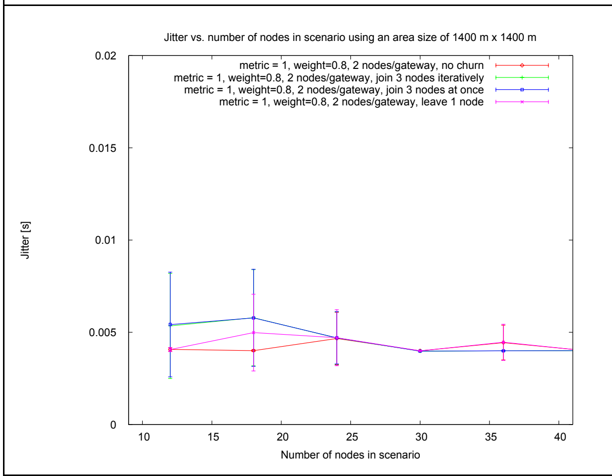
Scenario size 1400 m x 1400 m:



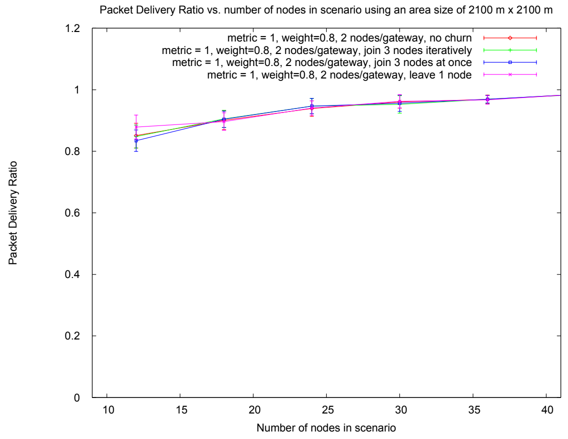


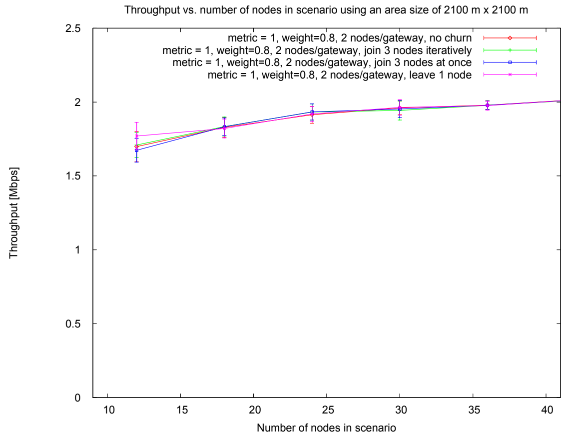


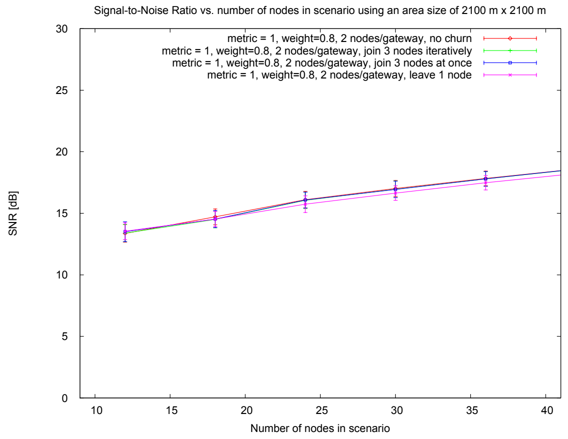


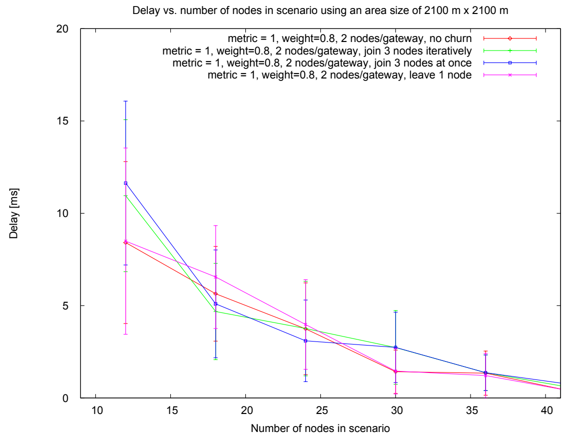


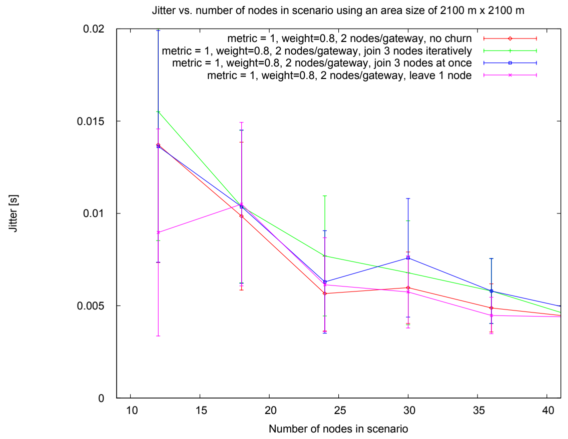
Scenario area size 2100 m x 2100 m:











Scenario size 2800 m x 2800 m: