Benchmarking Forwarding Protocols

Scenarios

CONTENTS

CHAPTER 1

Taxi Scenario

1.1 Description

This data set contains mobility traces of taxi cabs in San Francisco, USA. It contains GPS coordinates of approximately 500 taxis collected over 30 days in the San Francisco Bay Area.

Available at:https://crawdad.org/epfl/mobility/20090224/

Figure 1.1: SAN Taxi

Each taxi is equipped with a GPS receiver and sends a location-update (timestamp, identifier, geo-coordinates) to a central server. The location-updates are quite fine-grained - the average time interval between two consecutive location updates is less than 10 sec, allowing us to accurately interpolate node positions between location-updates.

The figure 1.2 depicts the coverage map of all the taxis and this is constructed with the GPS coordinates included in the trace files. The numbers of taxi journeys are higher in some main public ares such as city centre and the airport.

1.2 Trace Analysis

The following analysis is done with considering only the first 7 days of the trace file.

The figure 1.3 illustrate the number of contacts each node have. In X axis all the nodes are mentioned and in the Y axis the respective contact count is depicted. Almost all of the nodes contain more than 2000 contacts and one node contain more than 17500 contacts during the one week period.

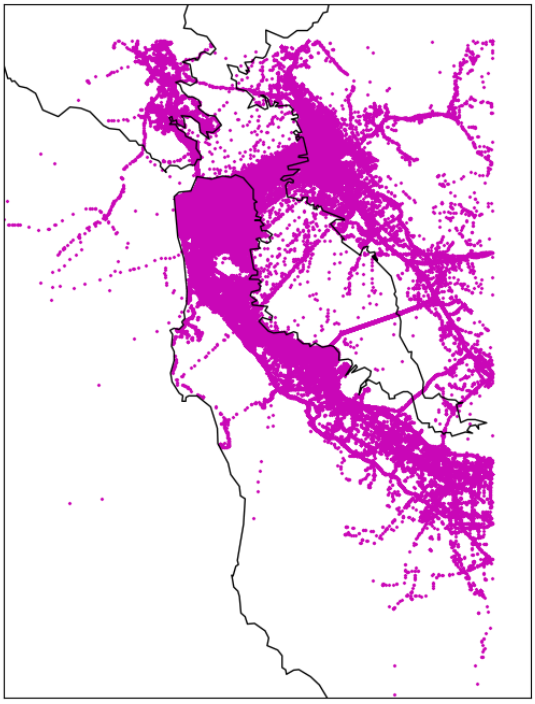

Figure 1.2: Taxi Coverage

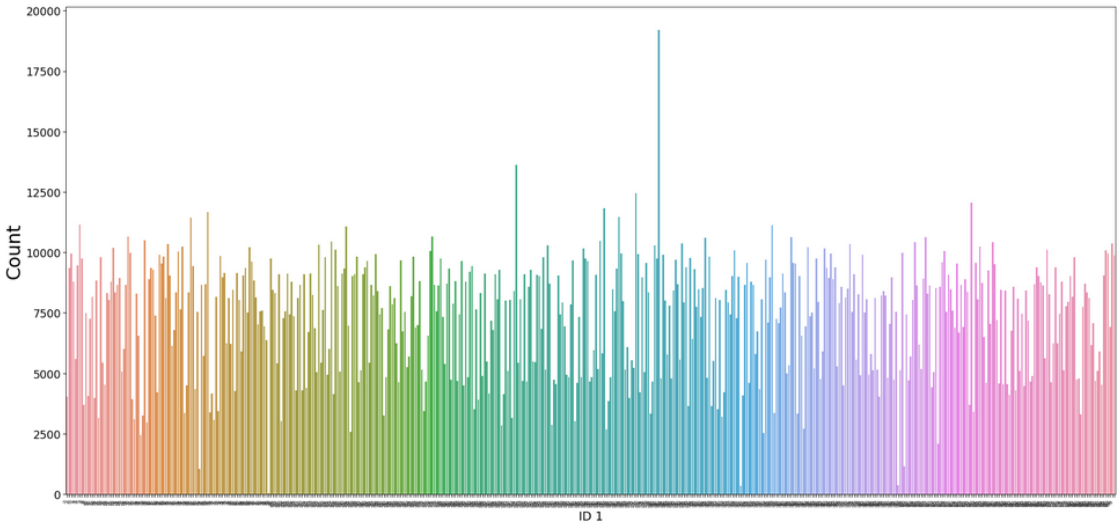

Figure 1.3: Number of Contacts

The figure 1.4 depicts the contact distribution with the time. In X axis the simulation time 604800 seconds (7 Days) in mentioned and in Y axis the number of contacts which starts at that particular second is illustrated. By observing, it is clear that during morning and evening there are more contacts. In contrast at the night time small number of contacts can be identified.

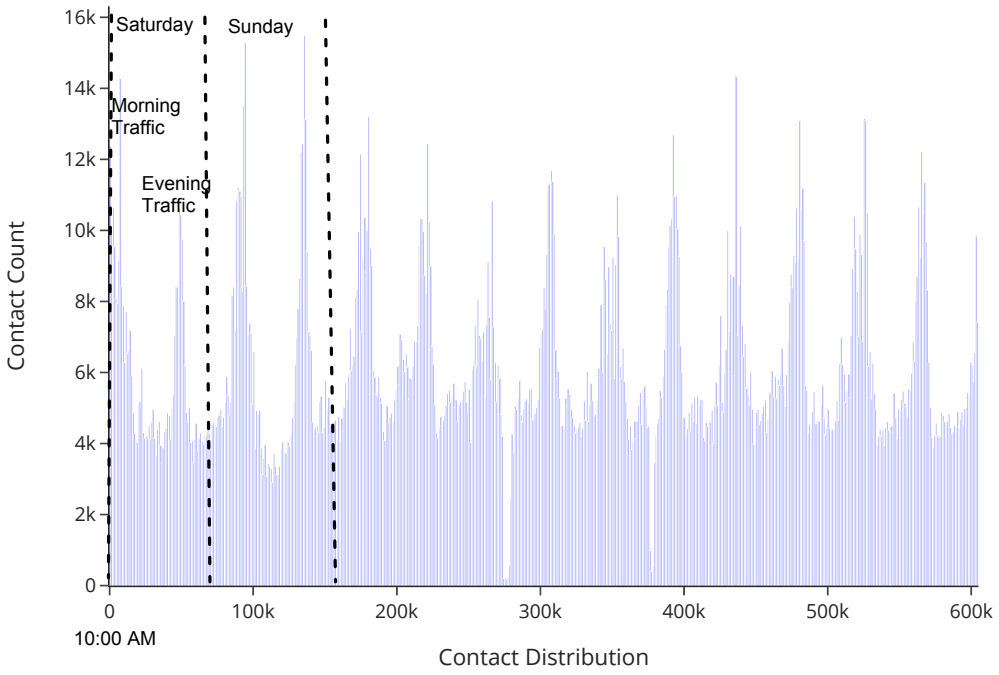

Figure 1.4: Contact Distribution

1.3 Scenario

By using the above mentioned trace the following taxi scenario was developed. In here the packet generation was divided into two main parts. Messages generated by the drivers and the messages generated by the Taxis.

In the table the type of messages generated and the size of the packet and the time to live (TTL) is also mentioned. Additionally for this scenario a cache size of 100 MB is used because in modern electronic equipment this much of space can be used without any issues.

The data generation pattern is illustrated with the figure 1.6. In the early morning very small demand is expected. Therefore the packet generation is also reduced. During morning office hours and evening higher demand is expected and higher number of packets are generated. Additionally to make the scenario more realistic a special event is introduced such as a accident or maintenance case. During these events very high number of packet are generated.

Taxi	Taxi Drivers
Messages 2 KB – 20 KB Traffic information - 15 min Emergency - 10 min Accident - 10 min Vehicle performance - 30 min	**Messages 2 KB – 40 KB** Possible passengers - 5 min Images – 30 min Traffic - 15 min Emergency - 10 min Requesting help - 10 min
Cache Size : 100 MB	

Figure 1.5: Types of Messages

Some information about the simulation:

- Nodes - 500
- Time - 604,800 seconds (7 days)
- Packet Sizes - (2 kB - 40 kB)
- Time to Live - (5 min - 30 min)
- Cache - 100 MB

The figure 1.6 shows the traffic generation frequency intervals for higher traffic and lower traffic scenarios separately. According to these generation intervals a value is selected randomly as the packet generation interval. If the generation interval is small, traffic is generated more often and if the generation interval is large, traffic is generated more sparsely.

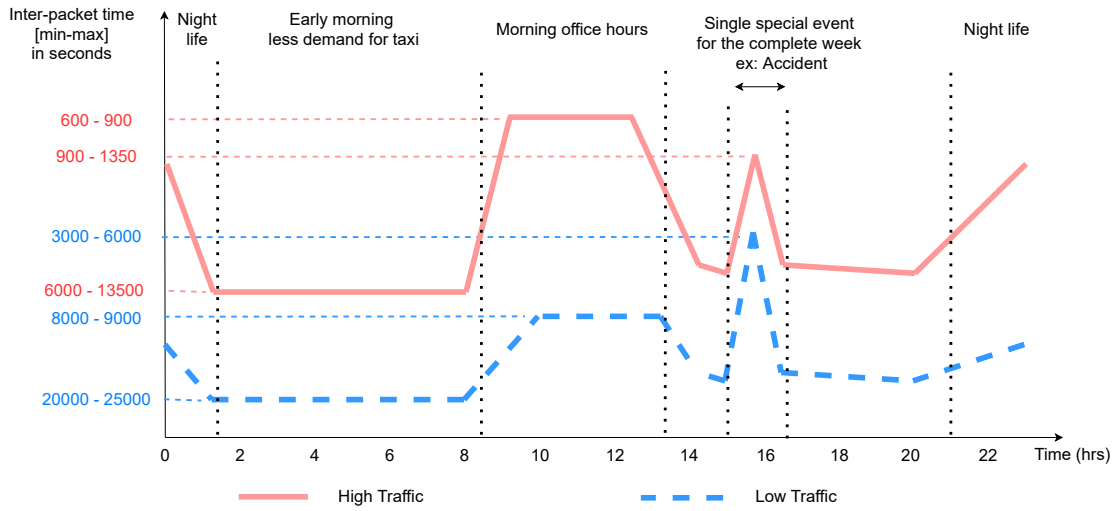

Figure 1.6: Packet Generation

- Number of packets with higher traffic- 105,299
- Number of packets with lower traffic - 18,546

The figure 1.7 shows the results obtain for this scenario with different forwarding protocols. Furthermore, figure 1.8 depicts the simulation statistics in OOTB with Epidemic routing protocol.

Parameter	Epidemic		RRS		Keetchi		Optmum Delay	
	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic
Delivery Ratio	0.075475	0.41161	0.103784	0.322046	0.045235	0.1198545		
Delivery Delay (s)	217473.600218	133819.753034	216848.621816	192074.91536	2277.416992	3322.588096087		
All data sent (bytes)	2767520936114	367918301976	365717575410	370137966207	131770851683	139266630179		
Average Hops	3.13559	3.769551	7.397965	8.7070160	8.961823	11.352471		
Average Neighbour Size	4.2095233134921		4.2095233134921		4.2095233134921			
Average Contact Duration (s)	56.903189754564		56.903189754564		56.903189754564			
Total Contact Count	1301887		1301887		1301887			

Figure 1.7: Taxi Scenario Results

Simulation Run Statistics

Start Wall Clock Time - 2021-01-08 10:28:03

Simulation Run Wall Clock Time - 279,903.0 seconds

Simulated Time - 604,800.0 seconds

Total Events - 3,992,018,299 events

Events per Wall Clock Second - 19,990.1 events

Simulation Seconds per Wall Clock Second - 0.0 seconds

Events per Simulation Second - 0.0 events

Total Messages Created - 591,499,474 messages

Results Parsing Wall Clock Time - 16,252.650132417679 seconds

Total Wall Clock Time - 296,155.6501324177 seconds

Peak Disk Space Used - 196,301,717,717 bytes

Peak RAM Used (Simulation) - 182,602,231,808 bytes

Peak RAM Used (Results Parsing) - 38,262,857,728 bytes

Configuration file - omnetpp.ini

Configuration - Config Benchmark-01-Taxi-Scenario

Figure 1.8: Simulation Statistics with Epidemic (High Traffic)

CHAPTER 2

Disaster Scenario

This dataset contains geolocation information for thousands of Twitter users during natural disasters in their area. These tweets are collected during 15 natural disasters. These disasters are divided into 5 main categories.

- Typhoon
- Earthquake
- Winter Storm
- Thunder Storm
- Wildfire

The following table depicts how many tweets and how many twitter uses are categorized into these disaster cases.

Type	Name	Location	No. of Tweets	No. of Users
Typhoon	Wipha (Tokyo)	Tokyo, Japan	849,173	73,451
	Halong (Okinawa)	Okinawa, Japan	166,325	5,124
	Kalmaegi (Calasiao)	Calasiao, Philippines	21,698	1,063
	Rammasun (Manila)	Manila, Philippines	408,760	27,753
Earthquake	Bohol (Bohol)	Bohol, Philippines	114,606	7,942
	Iquique (Iquique)	Iquique, Chile	15,297	1,470
	Napa (Napa)	Napa, USA	38,019	1,850
Winter storm	Xaver (Norfolk)	Norfolk, Britain	115,018	8,498
	Xaver (Hamburg)	Hamburg, Germany	15,054	2,745
	Storm (Atlanta)	Atlanta, USA	157,179	15,783
Thunderstorm	Storm (Phoenix)	Phoenix, USA	579,735	23,132
	Storm (Detroit)	Detroit, USA	765,353	15,949
	Storm (Baltimore)	Baltimore, USA	328,881	14,582
Wildfire	New South Wales[a] (1)	New South Wales, Australia (1)	64,371	9,246
	New South Wales[a] (2)	New South Wales, Australia (2)	34,157	4,147

Figure 2.1: Tweets

Available at:https://www.kaggle.com/dryad/human-mobility-during-natural-disasters

2.1 Typhoon-Halong

Typhoon Halong, known in the Philippines as Typhoon Jose, was a very powerful tropical cyclone in the Western Pacific asia in August 2014. The storm reached its maximum intensity as a Category 5 super typhoon, making it the fifth strongest storm of the season.

- Formed:July 27, 2014
- Dissipated:August 15, 2014
- Highest winds:10-minute sustained: 195 km/h (120 mph)
- 920 hPa (mbar):27.17 inHg

Figure 2.2: Typhoon

2.1.1 Trace Analysis

This trace contains 166,325 tweets uploaded by 5,124 users. The trace begins on 22nd July 2014 at 3am and trace lasted for one month and stops on 25th August 2014 at 2.59am. By analyzing weather information it is found that the typhoon hits the city of Okinawa on 10th August 2014 at 6am. Therefore the trace is filtered for a two days period to cover the typhoon effect. From the weather information it is mentioned that typhoon lasted for 6 hours.

The figure 2.3 depicts the number of contacts corresponding each node. In X axis all 5000 nodes are displayed and in Y axis the corresponding number of contacts are depicted.

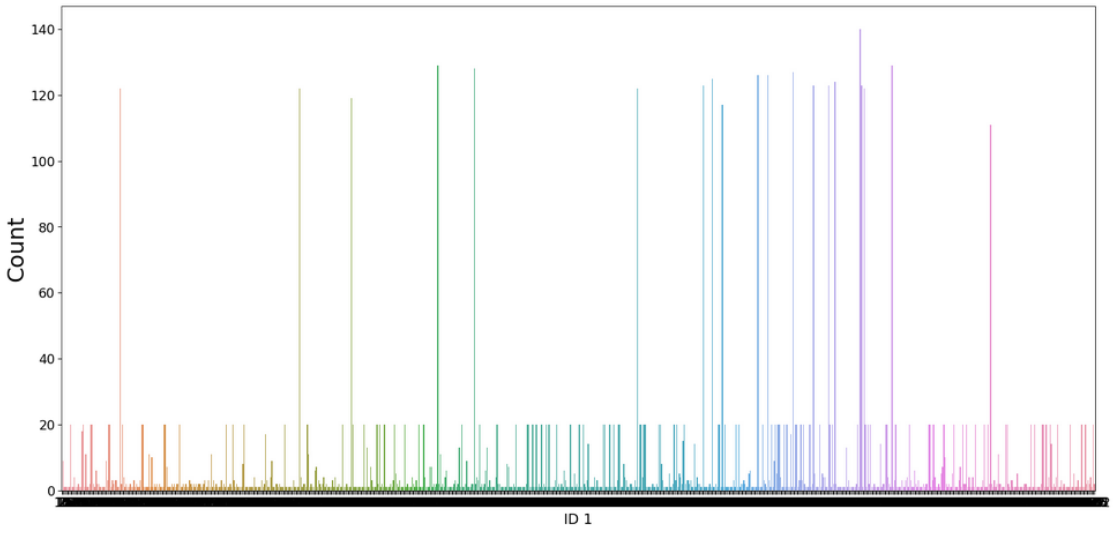

Figure 2.3: Contact Count

In figure 2.4 the contact distribution is illustrated. The first 15 hours are conidered as the pre-disaster duration. The typhoon continues for 6 hours and other 27 hours are considered as the post-disaster time.

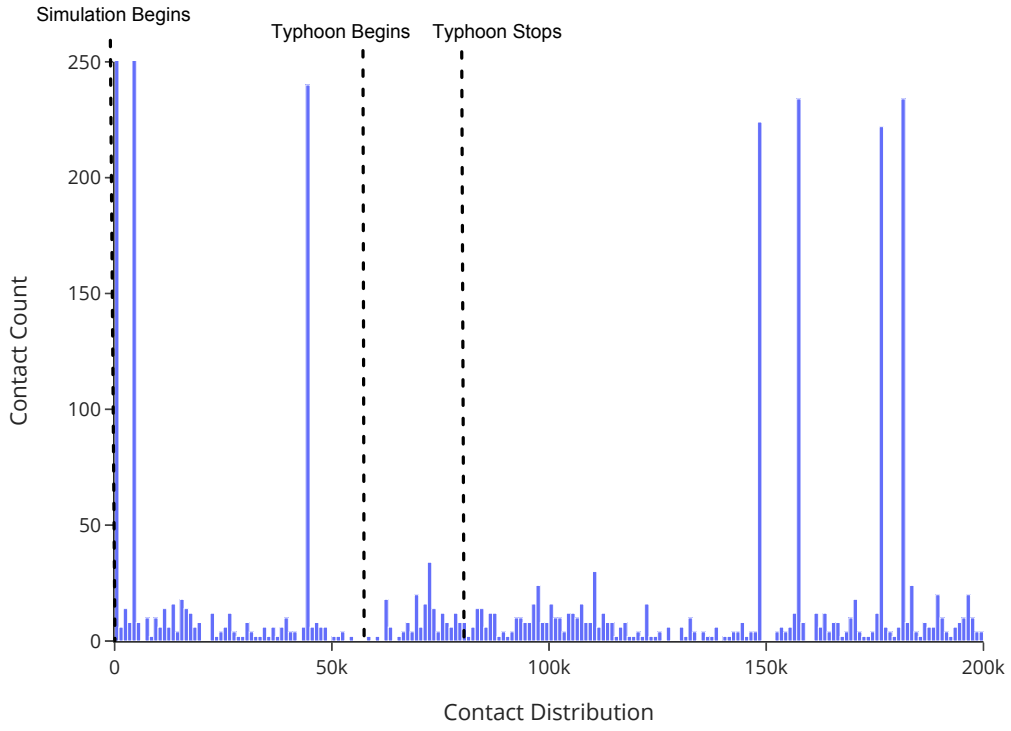

Figure 2.4: Contact Distribution

2.1.2 Scenario

After filtering the trace the number of nodes are reduced from 5000 to 3600. Therefore for the simulation these 3600 nodes are used and the duration is fixed for 2 days.

Some information about the simulation:

- Nodes - 3,600
- Time - 200,000 seconds (2+ days)
- Packet Sizes - (10 kB - 100 kB)
- Time to Live - (2 hrs - 20 hrs)
- Cache - 100 MB

The packet generation is done with the actual timing of the tweets. After filtering there are over 12,000 tweets generated by the 3600 nodes as depicted in figure 2.5. These timings are used to inject packets into the simulation. The datasizes of packets are calculated between 10KB and 100KB to mimic small text messages to images.

- Number of packets - 12,566

The figure 2.6 shows the results obtain for this scenario with different forwarding protocols. In figure 2.7 the obtained delivery ratios are compared graphically and the table 2.1 illustrate the performance ranking of the used protocol in terms of delivery ratios.

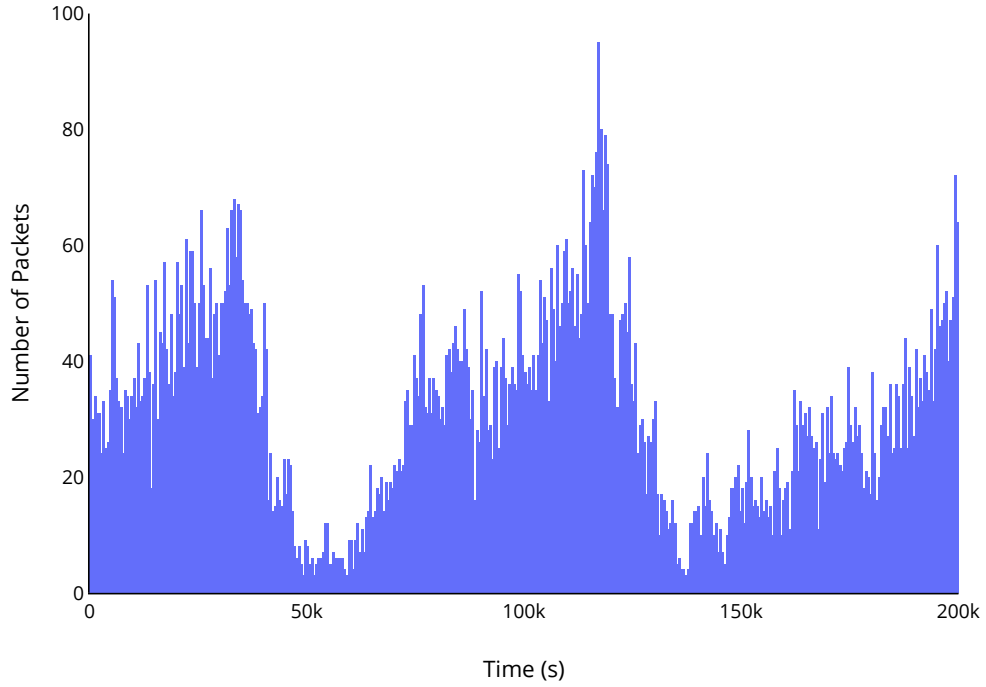

Figure 2.5: Typhoon Data Generation Pattern

Parameter	Epidemic	RRS	Keetchi	Optmum Delay
	High Traffic	High Traffic	High Traffic	High Traffic
Delivery Ratio	0.00067452845634313	0.0014006392808732	0.00019688855066657	0.0023375678853703
Delivery Delay (s)	24615.788647442	10982.207963746	43419.082089792	38665.180978955
All data sent (bytes)	535538349890	502789061743	12155568117	25883714717
Average Hops	2.5871574668939	29.056607049835	16.435597978664	1.5924426578387
Average Neighbour Size	3.7880995194444	3.7880995194444	3.7880995194444	3.7880995194444
Average Contact Duration (s)	5768.2279929577	5768.2279929577	5768.2279929577	5768.2279929577
Total Contact Count	1136	1136	1136	1136

Figure 2.6: Typhoon Scenario Results

The figure 2.8 depicts the simulation statistics in OOTB with Epidemic routing protocol.

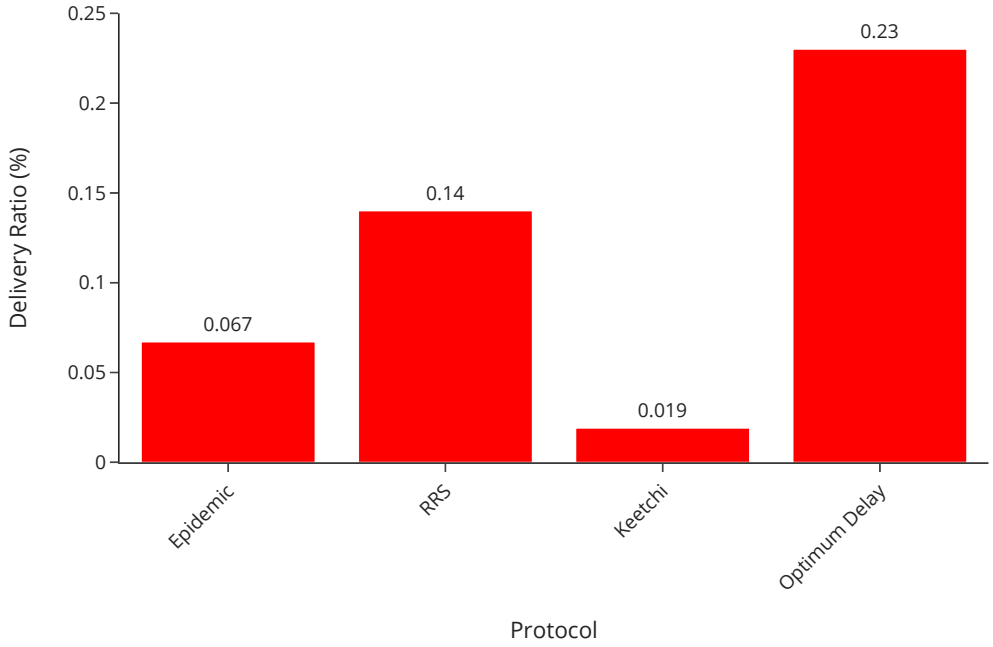

Figure 2.7: Delivery Ratio Comparison

Ranking	High Traffic
1	Optimum Delay
2	RRS
3	Epidemic
4	Keetchi

Table 2.1: Delivery Ratio Ranking of Protocols

Simulation Run Statistics

Start Wall Clock Time - 2021-01-27 13:17:52

Simulation Run Wall Clock Time - 90,377.9 seconds

Simulated Time - 200,000.0 seconds

Total Events - 7,899,959,470 events

Events per Wall Clock Second - 80,675.6 events

Simulation Seconds per Wall Clock Second - 1.92677 seconds

Events per Simulation Second - 41,871.0 events

Total Messages Created - 860,943,889 messages

Results Parsing Wall Clock Time - 40,031.402329444885 seconds

Total Wall Clock Time - 130,409.30232944488 seconds

Peak Disk Space Used - 237,811,995,041 bytes

Peak RAM Used (Simulation) - 102,761,095,168 bytes

Peak RAM Used (Results Parsing) - 106,292,158,464 bytes

Configuration file - omnetpp.ini

Configuration - Config Benchmark-02-Typhoon-Disaster-Scenario

Figure 2.8: Simulation Statistics with Epidemic

CHAPTER 3

Conference Scenario

3.1 Description

This trace contains contacts collected during Infocom 2006 in Barcelona. The location of the experiment is Princesa Sofia Gran Hotel, Barcelona and the duration was Monday, April 24th 2006 to Thursday April 27th 2006. The devices are distributed on Sundary April 23rd, between 7:00 and 9:00 pm and collected back starting from April 26th and on April 27th during the day.

During the experiment 98 devices were used with 20 static nodes deployed through out the hotel. The locations of the static nodes are as follows.

- Mezzanine floor- 6 nodes
- Floor 1 - 3 nodes
- Floor 2 - 6 nodes
- Lifts - 3 nodes
- Bar - 1 node
- Concierge - 1 node

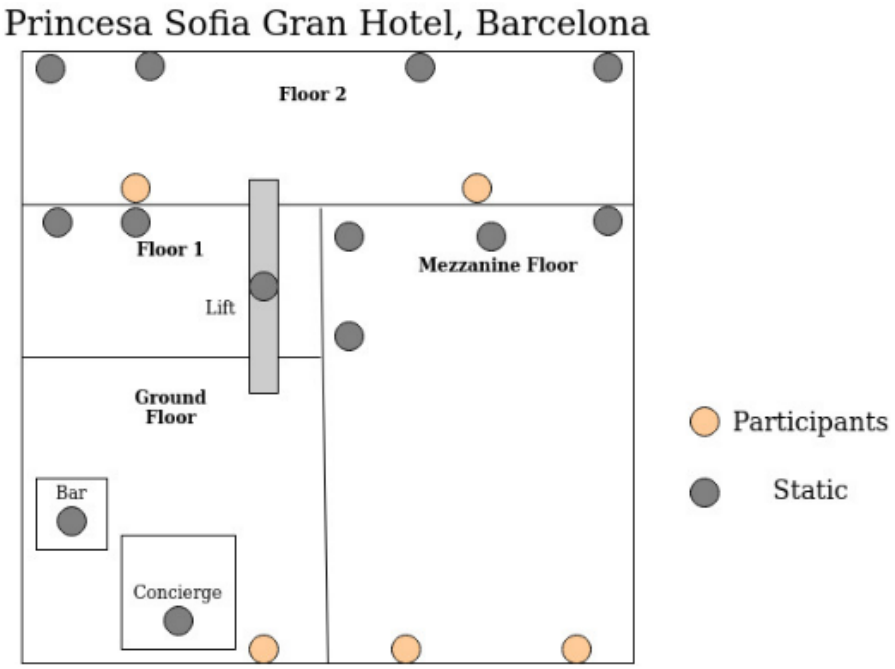

Figure 3.1: Node Distribution

Reference:https://crawdad.org/cambridge/haggle/20090529/
Available at:https://crawdad.org/cambridge/haggle/20090529/

3.2 Trace Analysis

The figure 3.2 depicts the number of contacts corresponding each node. In X axis all 98 nodes are displayed and in Y axis the corresponding number of contacts are depicted. Every node during the experiment duration was able gather at least 500 contacts and there are many nodes depicted contact count more than 2000.

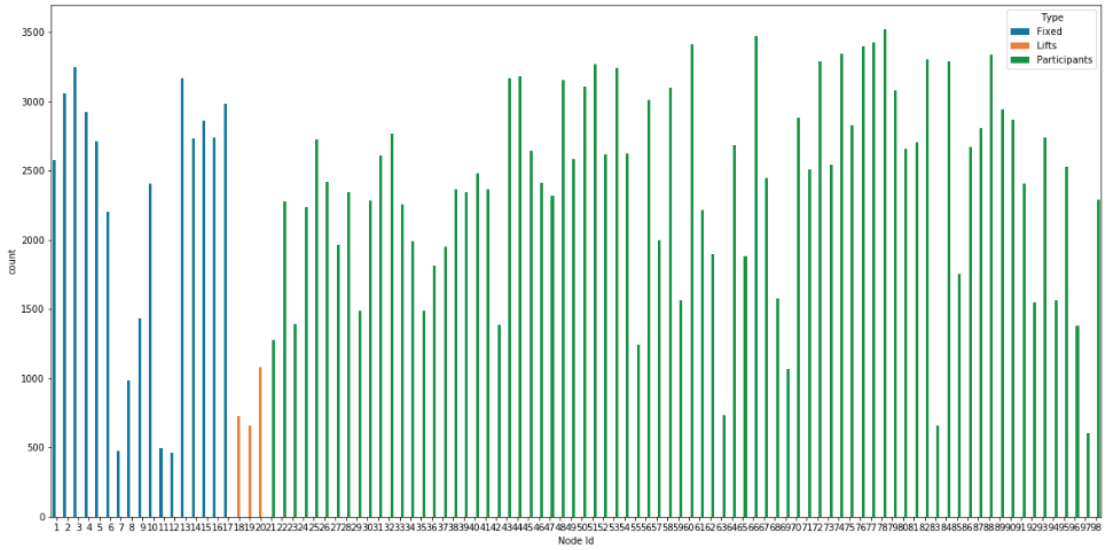

Figure 3.2: Contact Count

The figure 3.3 depicts the contact distribution with the time. The first peak corresponds to the time where all the devices were switched on and from 50,000 seconds on-wards the behaviour of the conference can be observed. From morning until the evening there are many contacts compared to nights. The last day displays the smallest amount of contacts from all three days.

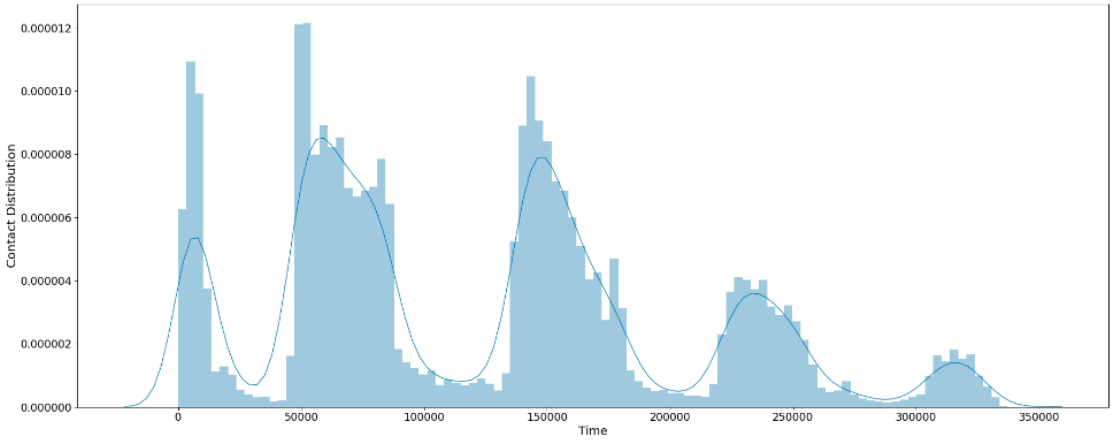

Figure 3.3: Contact Distribution

In figure 3.4 the contact distribution is depicted separately for each node. The node rep-

resenting green colour illustrate more contacts than other nodes. Therefore during the developed scenario these nodes will be considered as organizers.

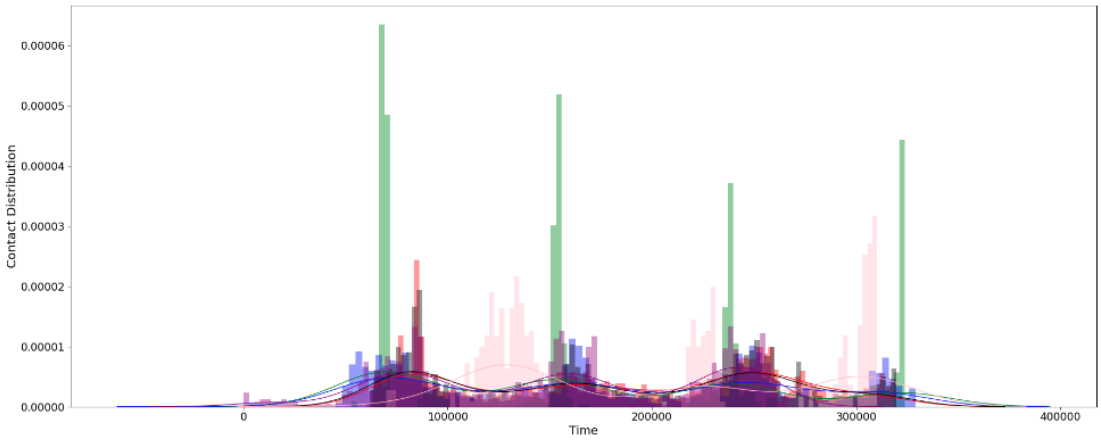

Figure 3.4: Number Of Contacts

3.3 Scenario

By using the above mentioned trace the following scenario was developed. In here the packet generation was divided into three main parts. Messages generated by the organizers,messages generated by the participants and hotel.

In the table the type of messages generated and the size of the packet and the time to live (TTL) is also mentioned. Additionally for this scenario a cache size of 100 MB is used.

Organizers	Participants	Hotel
Messages Location information – 2 KB – 15 min Security information – 1 KB - 25 min Schedule Information – 1 KB – 30 min	**Messages** Location information – 2 KB – 15 min Security information – 1 KB – 20 min **Images** Whatsapp – 50 KB	**Messages** Security information – 1 KB – 20 min Hotel promotions and deals – 3 KB – 15 min Restaurant Menu Info – 4 KB – 20 min **Images** Whatsapp – 50 KB
Cache Size : 100 MB		

Figure 3.5: Types of Messages

Some information about the simulation:

- Nodes - 98
- Time - 250,000 seconds (3 days)
- Packet Sizes - (0.2 kB - 50 kB)
- Time to Live - (15 min - 30 min)
- Cache - 100 MB

The handcrafted traffic is presented in figure 3.6. For this scenario, we decided for a more complex packet generation scenario, which mimics the communications of organizers (the top of figure 3.6, like program or social events updates; lower traffic from the hotel itself (e.g. about lunch offers, peaking around lunchtime); and from the participants with peaks around the conference breaks and some non-zero traffic during the evenings.
The data generation pattern is illustrated with the figure 3.6. During the packet generation a morning breakfast and a lunch is considered. In these events organizers generate small number of packets. The organizers are expect to generate more packets in the beginning of the section.

Participants are expect to generate more data during the breakfast and the lunch. Additionally, after the evening there may be small gatherings and these events will last until midnight.

The figure 3.6 shows the traffic generation frequency intervals for higher traffic and lower traffic scenarios separately. According to these generation intervals a value is selected randomly as the packet generation interval. If the generation interval is small, traffic is generated more often and if the generation interval is large, traffic is generated more sparsely.

- Number of packets with higher traffic- 9103
- Number of packets with lower traffic - 3837

The figure 3.7 shows the results obtain for this scenario with different forwarding protocols with high traffic and low traffic. In figure 3.8 the obtained delivery ratios are compared graphically and the table 3.1 illustrate the performance ranking of the used protocol in terms of delivery ratios.

Ranking	**High Traffic**	**Low Traffic**
1	Optimum Delay	Optimum Delay
2	Epidemic	Epidemic
3	RRS	RRS
4	Keetchi	Keetchi

Table 3.1: Delivery Ratio Ranking of Protocols

Furthermore, figure 3.9 depicts the simulation statistics in OOTB with Epidemic routing protocol.

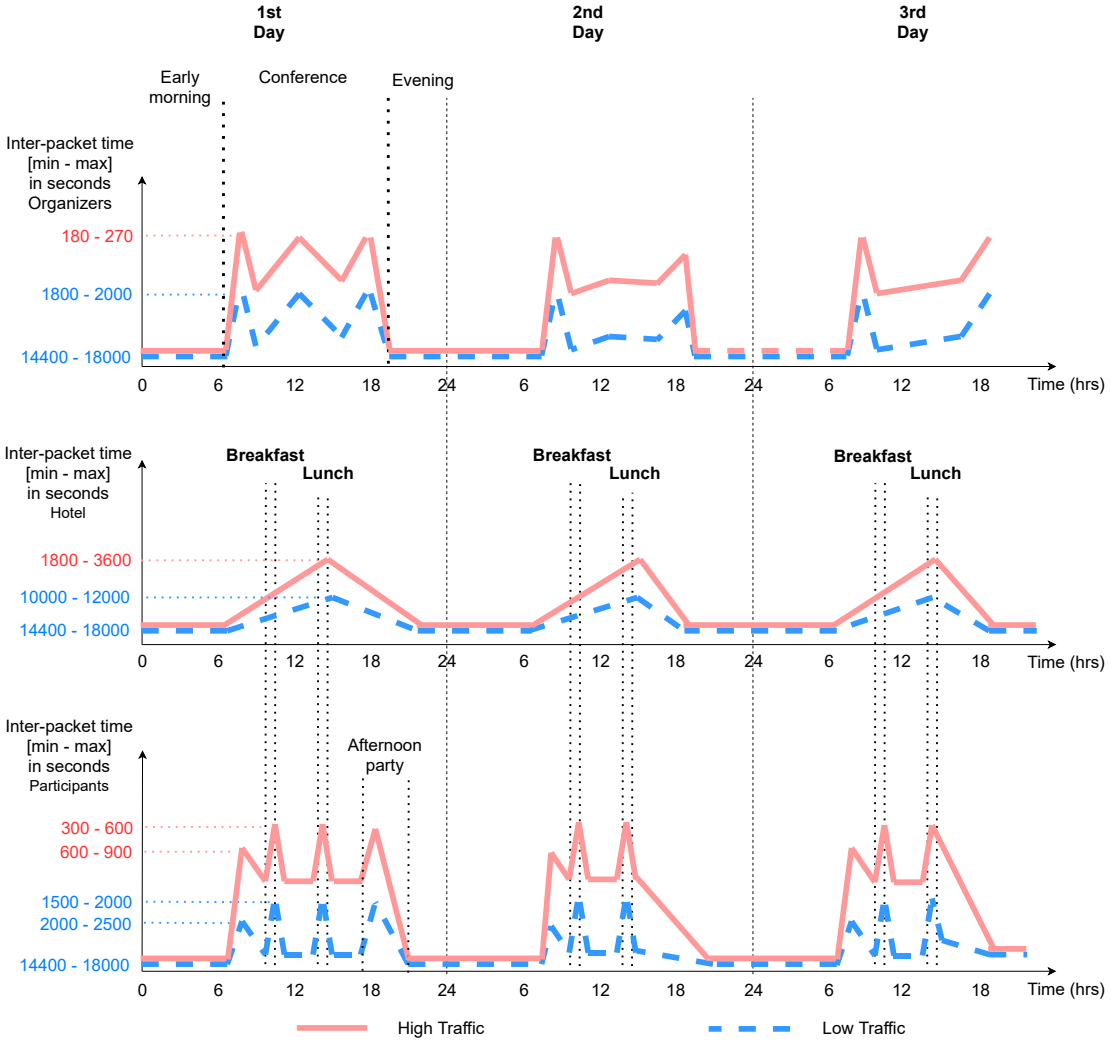

Figure 3.6: Packet Generation

Parameter	Epidemic		RRS		Keetchi		Optmum Delay	
	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic
Delivery Ratio	0.39457562553222	0.60288058105865	0.31798982660845	0.45877094491869	0.07319429094 2692	0.10542969652364	0.82577047814034	0.83313635215936
Delivery Delay (s)	53160.400759844	38940.22477894	68258.684316434	61244.460836208	5099.5091613968	8113.959812358	16096.579744709	16462.588359413
All data sent (bytes)	42717166573	12544131024	54266117078	55052901978	12207875015	11997230290	19647339691	8345273924
Average Hops	4.0622049390865	4.6140418099838	10.084643517216	13.271806972142	8.4572149078701	11.658700636943	5.3819189608737	5.3084809698064
Average Neighbour Size	1.0356204897959		1.0356204897959		1.0356204897959		1.0356204897959	
Average Contact Duration (s)	1050.3012731251		1050.3012731251		1050.3012731251		1050.3012731251	
Total Contact Count	10054		10054		10054		10054	

Figure 3.7: Conference Scenario Results

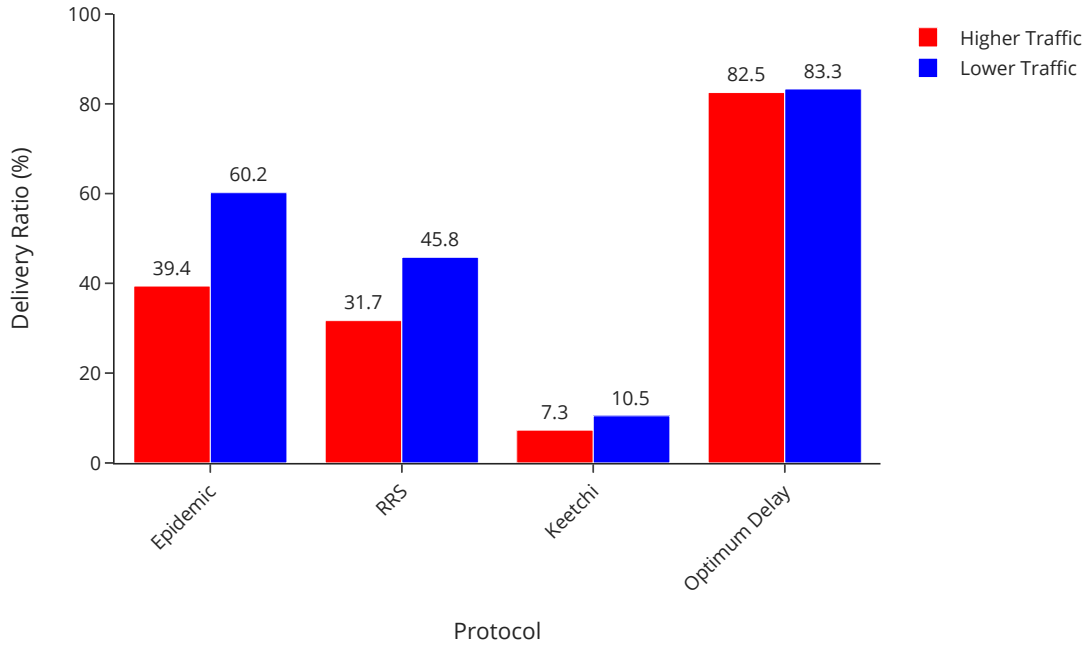

Figure 3.8: Delivery Ratio Comparison

Simulation Run Statistics

Start Wall Clock Time - 2021-01-26 09:05:37

Simulation Run Wall Clock Time - 3,609.65 seconds

Simulated Time - 250,000.0 seconds

Total Events - 55,690,977 events

Events per Wall Clock Second - 15,624.1 events

Simulation Seconds per Wall Clock Second - 71.9532 seconds

Events per Simulation Second - 217.143 events

Total Messages Created - 38,768,381 messages

Results Parsing Wall Clock Time - 597.7016816139221 seconds

Total Wall Clock Time - 4,207.351681613922 seconds

Peak Disk Space Used - 8,293,417,730 bytes

Peak RAM Used (Simulation) - 5,487,591,424 bytes

Peak RAM Used (Results Parsing) - 2,628,087,808 bytes

Configuration file - omnetpp.ini

Configuration - Config Benchmark-04-Conference-Scenario

Figure 3.9: Simulation Statistics with Epidemic (High Traffic)

CHAPTER 4

University Scenario

4.1 Description

This trace contains contacts of students from Cambridge University who were asked to carry these iMotes with them at all times for the duration of the experiment. In addition to this, a number of stationary nodes are deployed in various locations such as grocery stores, pubs, market places, and shopping centers in and around the city of Cambridge, UK. A stationary iMote was also placed at the reception of the Computer Lab, in which most of the experiment participants are students. The experiment was started on Friday, October 28th 2005, 9:55:32 and stopped on Wednesday, December 21th 2005, 13:00. Altogether 54 nodes are deployed and from these nodes 18 are fixed stationary and 36 are mobile participants.The locations of the static nodes are as follows.

- Pubs - 5 nodes
- Shop windows - 8 nodes
- Popular supermarket - 1 node
- Computer lab - 1 node
- Other - 3 nodes

Reference:https://crawdad.org/cambridge/haggle/20090529/
Available at:https://crawdad.org/cambridge/haggle/20090529/

4.2 Trace Analysis

The figure 4.1 depicts the number of contacts corresponding each node. In X axis all 54 nodes are displayed and in Y axis the corresponding number of contacts are depicted. Fixed nodes were able to depict higher number of contacts than students and some nodes have much more contacts than others. These nodes are located in popular places such as city centre and super market.

The figure 4.2 depicts the contact distribution with the time. As expected during the day time there are more contacts than the night time. Eventhough the trace is 2 months long, after 20 days there were no contacts recorded. A possible reason for this behaviour may be the battery inside the nodes. The handheld devices which were deployed among students contains the smallest batteries. Therefore when using the trace it is better to restrict the time duration to 7 days then it can be sure that all nodes are working.

4.3 Scenario

By using the above mentioned trace the following scenario was developed. In here the packet generation was divided into two main parts. Messages generated by the students

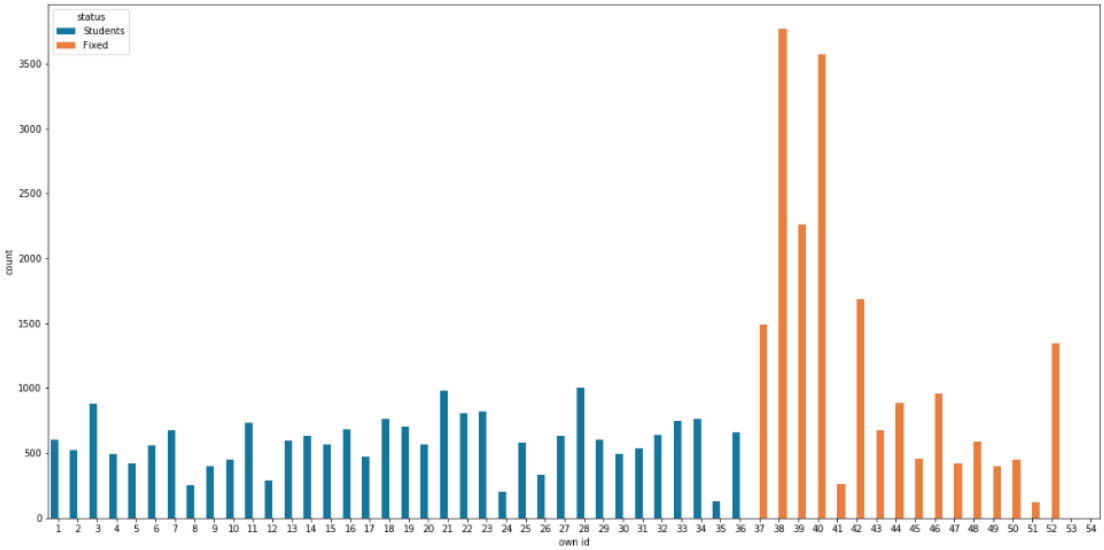

Figure 4.1: Contact Count

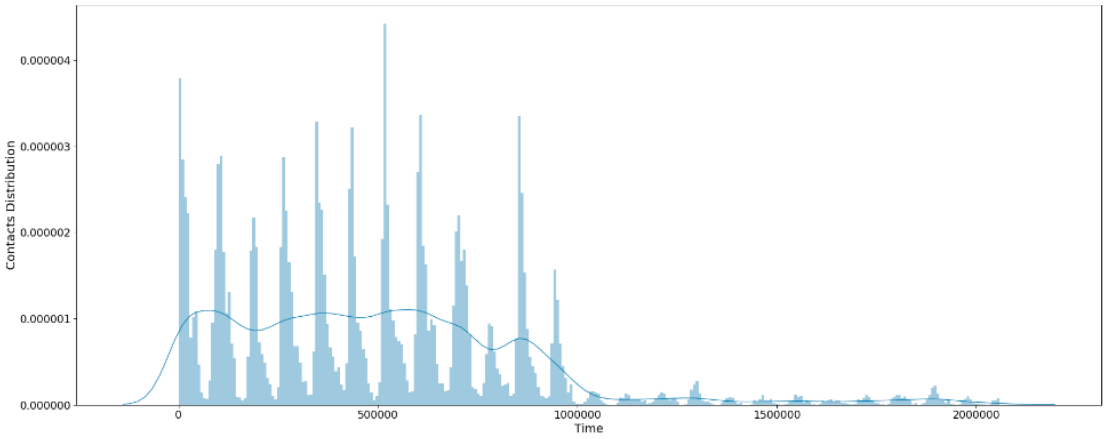

Figure 4.2: Contact Distribution

and messages generated by the shops(fixed nodes).

In the table the type of messages generated and the size of the packet and the time to live (TTL) is also mentioned. Additionally for this scenario a cache size of 100 MB is used.

Students	Fixed
Images and videos Whatsapp – 50 KB – 30 min **Messages** Information about special events - 1 KB – 15 min News and website links – 1.5 KB – 20 min Short text messages – 0.2 KB – 15 min	**Images** Whatsapp – 50 KB – 1 hr **Messages** Sales and promotion information – 0.5 KB – 20 min Security Information- 3 KB – 45 min Upcoming Events – 4 KB – 30 min
Cache Size : 100 MB	

Figure 4.3: Types of Messages

Some information about the simulation:

- Nodes - 54
- Time - 604,800 seconds (7 days)
- Packet Sizes - (0.2 kB - 50 kB)
- Time to Live - (15 min - 120 min)
- Cache - 100 MB

The data generation pattern is illustrated with the figure 4.4. During the weekends small number of packets are generated and on sundays the shops are considered to be closed. Within 7 days one day is considered as a holiday to make the scenario realistic. Shops generate packets equally from 9am to 11pm. Students generate packets more often during the lunch and small number of packets will be generated during the night time.

The figure 4.4 shows the traffic generation frequency intervals for higher traffic and lower traffic scenarios separately. According to these generation intervals a value is selected randomly as the packet generation interval. If the generation interval is small, traffic is generated more often and if the generation interval is large, traffic is generated more sparsely. In this case, we assumed fixed and mobile nodes (students) would produce different types of traffic and that less traffic is produced during weekends from both groups of nodes.//

- Number of packets with higher traffic- 3317
- Number of packets with lower traffic - 1738

The figure 4.5 shows the results obtain for this scenario with different forwarding protocols with high traffic and low traffic. In figure 4.6 the obtained delivery ratios are compared

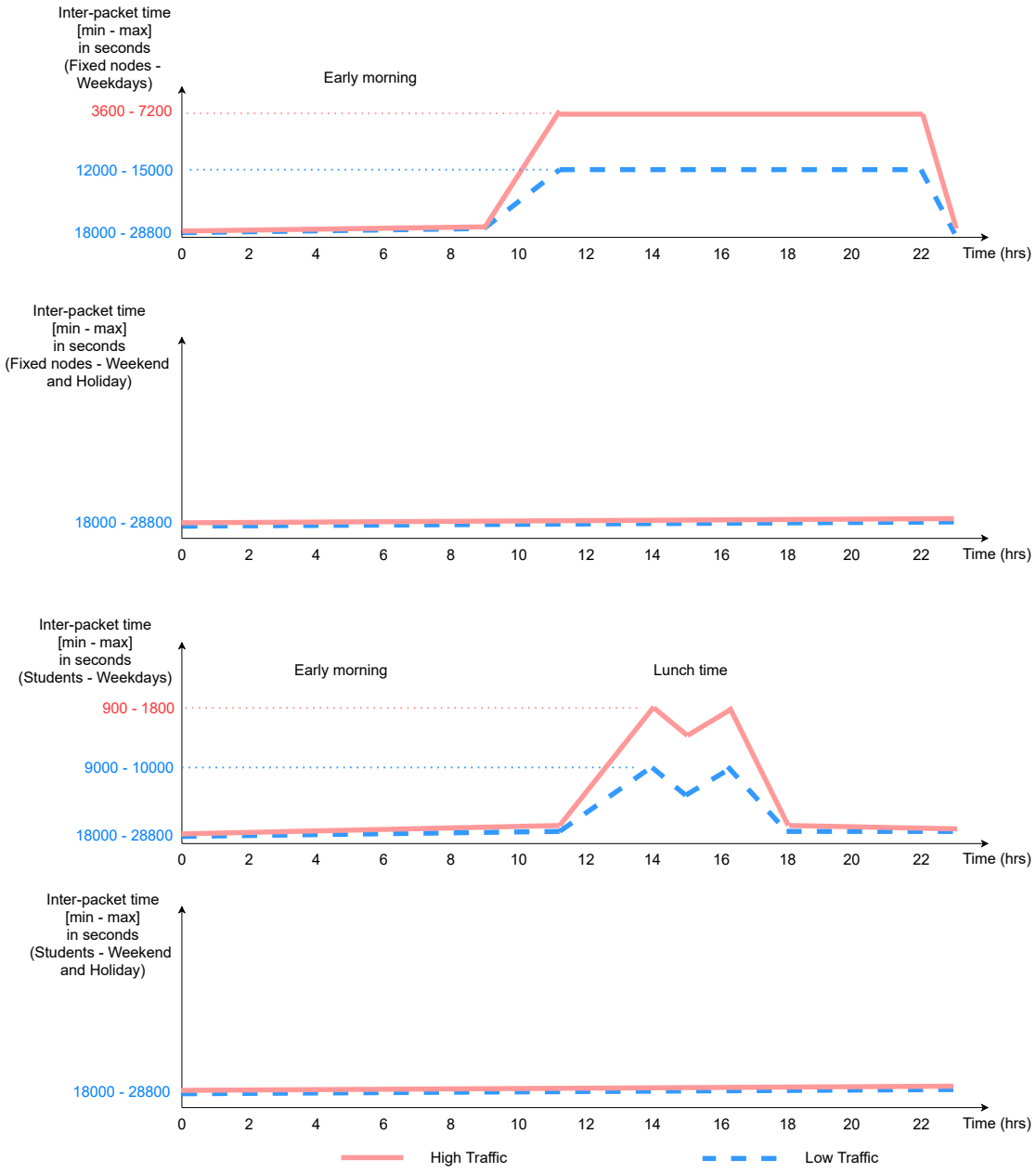

Figure 4.4: Packet Generation

graphically and the table 4.1 illustrate the performance ranking of the used protocol in terms of delivery ratios.

Parameter	Epidemic		RRS		Keetchi		Optmum Delay	
	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic
Delivery Ratio	0.32301795807886	0.30181084336042	0.28340555233319	0.31221586902037	0.057388515473063	0.091052111927262	0.6293516212312 5	0.60744084108195
Delivery Delay (s)	146181.2219068	131536.37977214	187109.28790693	154335.13551301	75060.528549655	139899.4404624	135259.40723726	136438.11575032
All data sent (bytes)	3114080595	1264635575	13563957337	13610391261	713195647	697779512	3070469226	1588505369
Average Hops	3.6888775438349	3.7917101053313	7.6006661583531	10.020920211287	5.6088981371383	5.1216634890372	3.4570721217269	3.4593112563855
Average Neighbour Size	0.35299079585538		0.35299079585538		0.35299079585538		0.35299079585538	
Average Contact Duration (s)	2538.0835509138		2538.0835509138		2538.0835509138		2538.0835509138	
Total Contact Count	766		766		766		766	

Figure 4.5: University Scenario Results

Ranking	High Traffic	Low Traffic
1	Optimum Delay	Optimum Delay
2	Epidemic	RRS
3	RRS	Epidemic
4	Keetchi	Keetchi

Table 4.1: Delivery Ratio Ranking of Protocols

Furthermore, figure 4.7 depicts the simulation statistics in OOTB with Epidemic routing protocol.

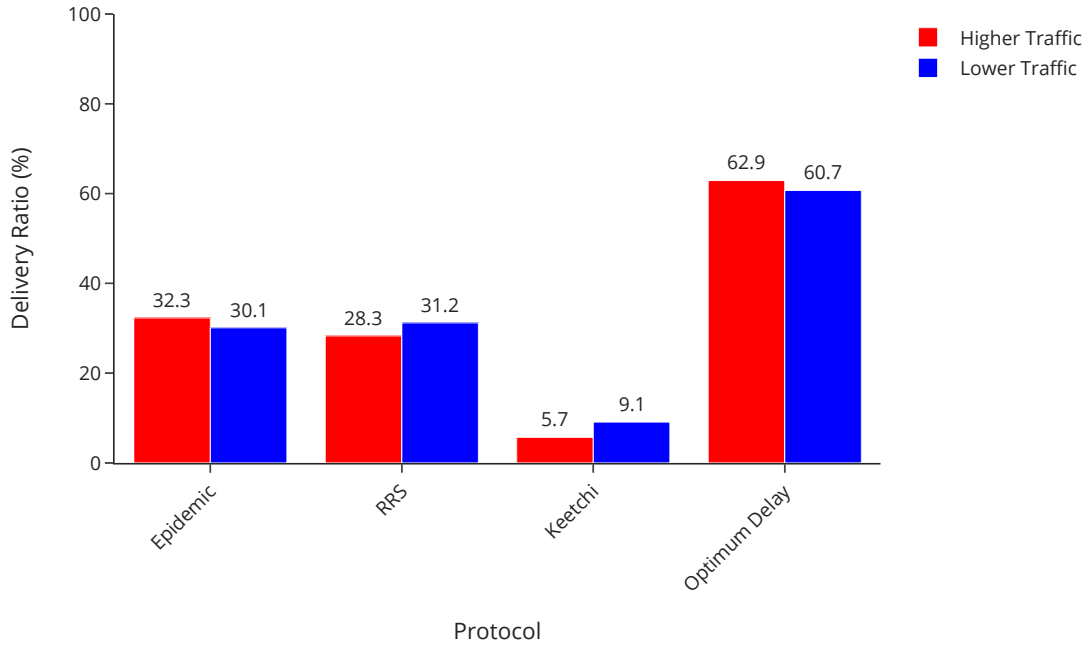

Figure 4.6: Delivery Ratio Comparison

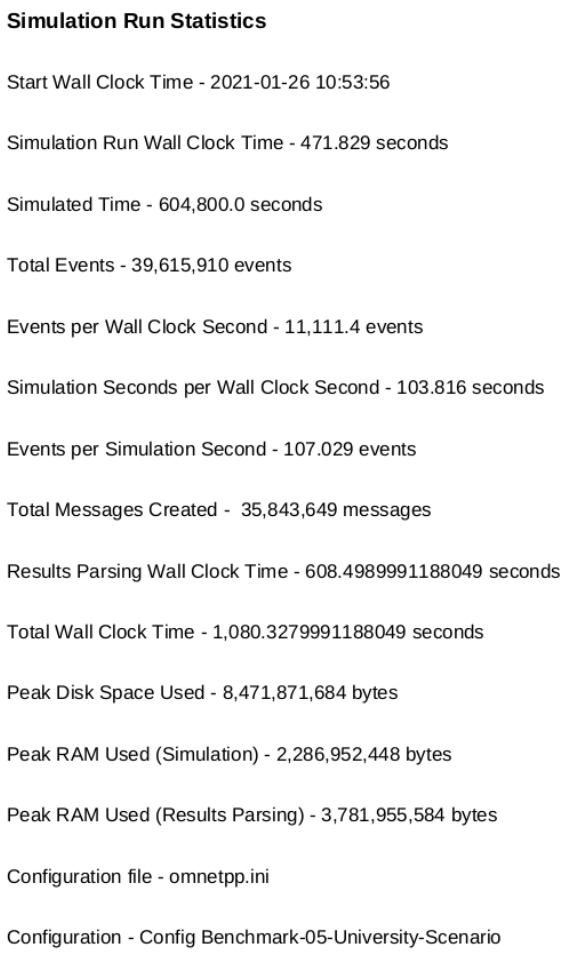

Figure 4.7: Simulation Statistics with Epidemic (High Traffic)

CHAPTER 5

Roller Skating Scenario

5.1 Description

Every Friday evening and every Sunday afternoon in Paris, weather permitting, groups of between 5,000 and 15,000 people go rollerblading. Over the course of three hours, the rollerbladers typically cover 30 km, crossing a large portion of the city. They are guided by staff members and assisted by public safety forces.

Figure 5.1: Skaters

Figure 5.2: Coverage

The data set has been collected on August 20, 2006. According to organizers and police information, about 2,500 people participated to the rollerblading tour (few rain showers just before the tour resulted in a number of participants below the average). The total duration of the tour was about three hours, composed of two sessions of 80 minutes, interspersed with a break of 20 minutes.

In the experiment, 62 iMotes were distributed to a group of people to collect any opportunistic sighting of other Bluetooth devices (including the other iMotes distributed). Distribution is as follows.

- 25 staff
- 26 professional skaters
- 11 set of friends

Reference:https://crawdad.org/upmc/rollernet/20090202/
Available at:https://crawdad.org/upmc/rollernet/20090202/

5.2 Trace Analysis

The figure 5.3 depicts the number of contacts corresponding each node. Here the skilled skaters depicts higher number of contacts because they are able to move faster than others. The nodes illustrated as friends depicts the lowest number of contacts.

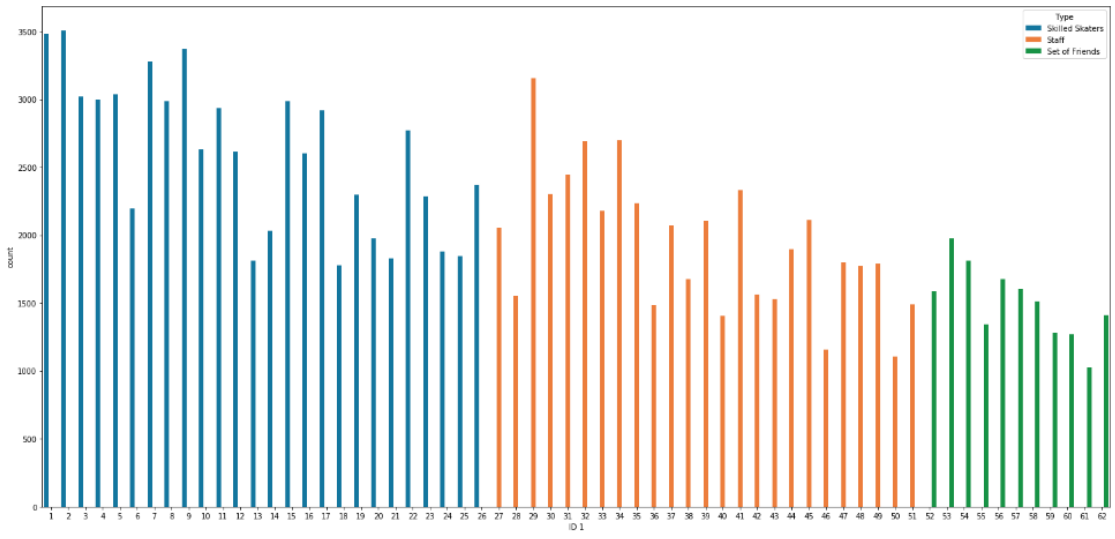

Figure 5.3: Contact Count

The figure 5.4 depicts the contact distribution with the time. Here the first 80 min (Before the break) shows the highest number of contacts. During the break (20 min) since nodes are relaxing and stationary there are less number of contacts.

In figure 5.5 the contacts are categorized into three main parts, before break, during break and after break. The main idea of this figure is to find out the reason of having smaller number of contacts after the break compared to first 80 min. The main reason for this behaviour is the small number of external contacts after the break. This can be result of some people leave the skating tour during the break.

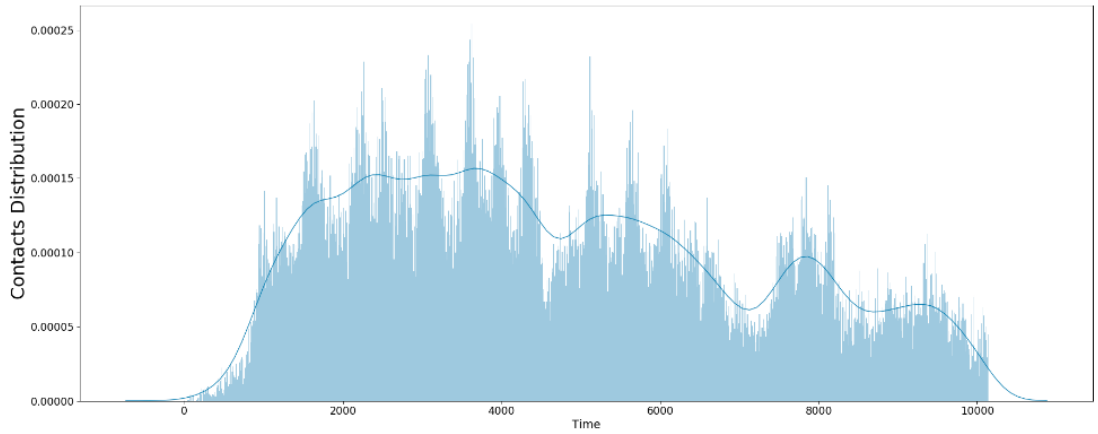

Figure 5.4: Contact Distribution

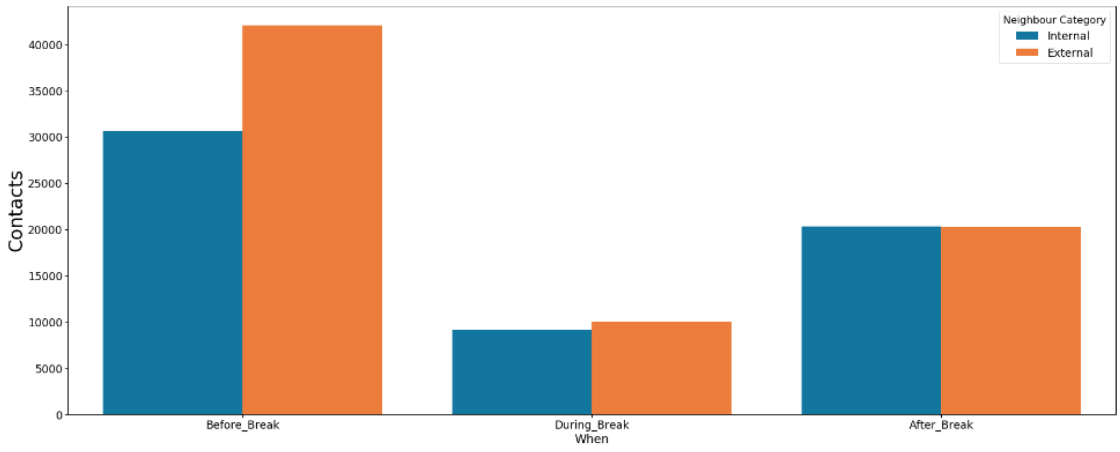

Figure 5.5: Number Of Contacts

5.3 Scenario

By using the above mentioned trace the following scenario was developed. In here the packet generation was divided into two main parts. Messages generated by the organizers and the messages generated by the participants.

In the table the type of messages generated and the size of the packet and the time to live (TTL) is also mentioned. Additionally for this scenario a cache size of 100 MB is used.

Organizers	Participants
Images Whatsapp – 40 KB – 20 min **Messages 0.2KB - 10 KB** Traffic Information – 10 min Route Information – 20 min Security Information – 20 min Upcoming Events – 15 min	**Images** Whatsapp – 50 KB – 15 min **Messages 0.2KB - 10 KB** Health Information – 10 min Security Information – 20 min Location Information – 10 min Short text messages – 15 min
Cache Size : 100 MB	

Figure 5.6: Types of Messages

Some information about the simulation:

- Nodes - 62
- Time - 10,800 seconds (3 hrs)
- Packet Sizes - (0.2 kB - 50 kB)
- Time to Live - (10 min - 20 min)
- Cache - 100 MB

The data generation pattern is illustrated with the figure 5.7. As depicted the organizers expect to generate more packets during the beginning phase and ending phase. Additionally before the break and the just after the break organizers generate more packets to indicate participants what to follow. All other times the packet generation of the organizers are considered to be low except special events such as traffic indication or an accident.

The participants are expect to generate more data during the beginning, ending and the break periods.

The figure 5.7 shows the traffic generation frequency intervals for higher traffic and lower traffic scenarios separately. According to these generation intervals a value is selected randomly as the packet generation interval. If the generation interval is small, traffic is generated more often and if the generation interval is large, traffic is generated more sparsely.//

- Number of packets with higher traffic- 1514
- Number of packets with lower traffic - 743

The figure 5.8 shows the results obtain for this scenario with different forwarding protocols with high traffic and low traffic. In figure 5.9 the obtained delivery ratios are compared

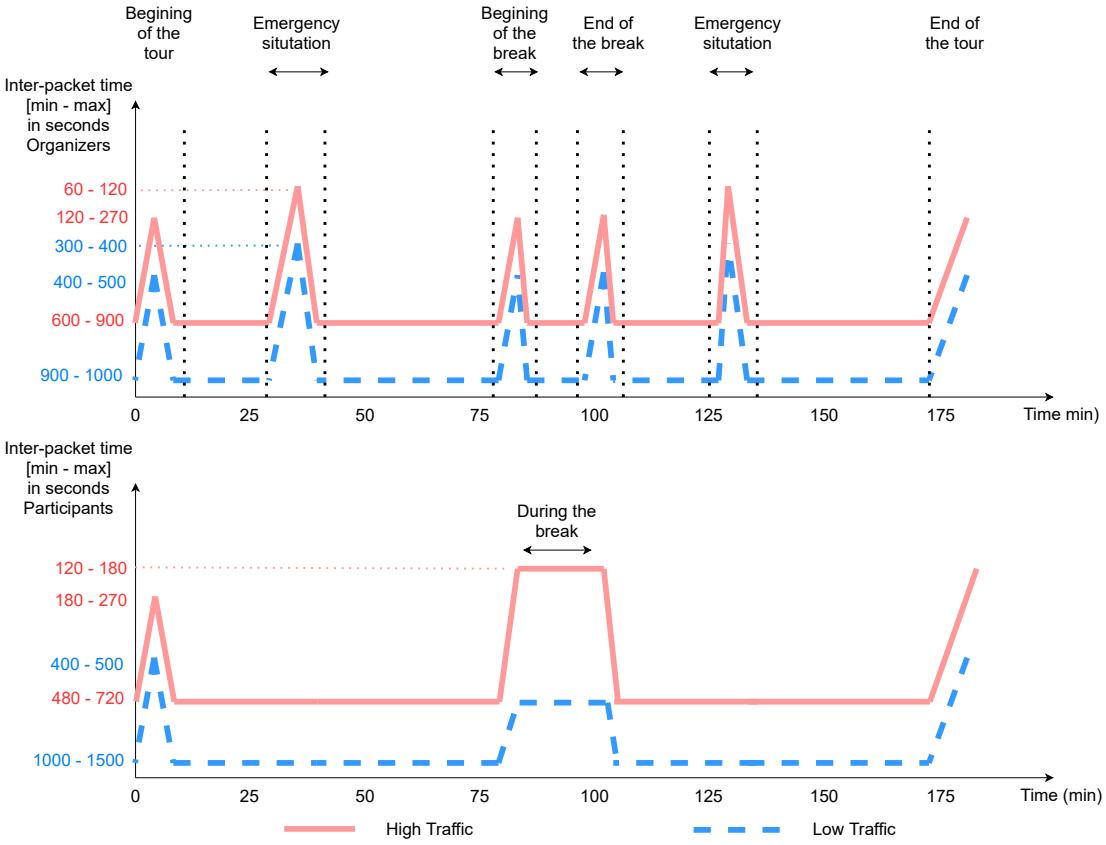

Figure 5.7: Packet Generation

graphically and the table 5.1 illustrate the performance ranking of the used protocol in terms of delivery ratios.

Parameter	Epidemic		RRS		Keetchi		Optmum Delay	
	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic
Delivery Ratio	0.3158578152897 3	0.7413185263529	0.2502732240437 2	0.3805085492684 6	0.0870421468376 35	0.13114754098 361	0.88107991126 982	0.9149039309 0076
Delivery Delay (s)	3806.9923915999	2481.9541763571	3375.6779416836	3082.8492467798	817.68306029836	743.563763051 07	173.187896837 91	194.02747459 206
All data sent (bytes)	4479290427	3715640489	2127488146	2185141608	5606057716	5595782159	2623895564	1365035305
Average Hops	2.380130181569	2.6795565331114	4.7381209736694	5.1767907811686	4.2688960716062	4.58165322580 65	5.70129567086 28	5.6965945763 692
Average Neighbour Size	1.2061917562724		1.2061917562724		1.2061917562724		1.2061917562724	
Average Contact Duration (s)	18.591263650546		18.591263650546		18.591263650546		18.591263650546	
Total Contact Count	21153		21153		21153		21153	

Figure 5.8: Roller Skate Scenario Results

Ranking	High Traffic	Low Traffic
1	Optimum Delay	Optimum Delay
2	Epidemic	Epidemic
3	RRS	RRS
4	Keetchi	Keetchi

Table 5.1: Delivery Ratio Ranking of Protocols

Furthermore, figure 5.10 depicts the simulation statistics in OOTB with Epidemic routing protocol.

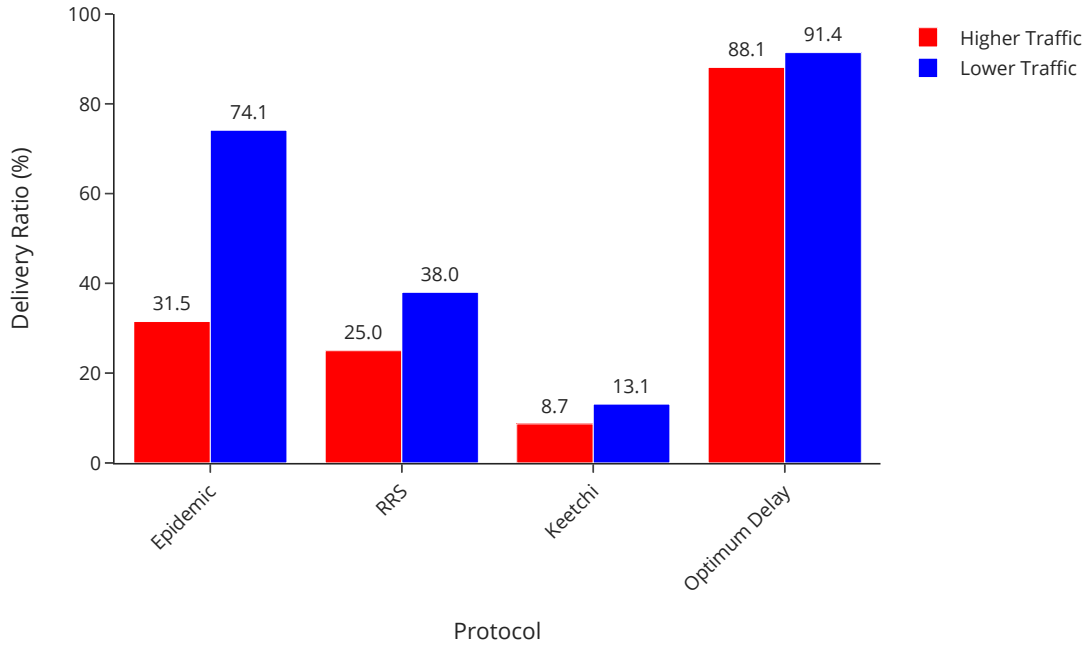

Figure 5.9: Delivery Ratio Comparison

Simulation Run Statistics

Start Wall Clock Time - 2021-01-26 11:33:35

Simulation Run Wall Clock Time - 14.179 seconds

Simulated Time - 10,800.0 seconds

Total Events - 2,288,421 events

Events per Wall Clock Second - 146,314.0 events

Simulation Seconds per Wall Clock Second - 864.939 seconds

Events per Simulation Second - 169.162 events

Total Messages Created - 1,390,424 messages

Results Parsing Wall Clock Time - 34.94408559799194 seconds

Total Wall Clock Time - 49.123085597991945 seconds

Peak Disk Space Used - 310,449,767 bytes

Peak RAM Used (Simulation) - 3,191,316,480 bytes

Peak RAM Used (Results Parsing) - 100,397,056 bytes

Configuration file - omnetpp.ini

Configuration - Config Benchmark-06-Roller-Skate-Scenario

Figure 5.10: Simulation Statistics with Epidemic (High Traffic)

CHAPTER 6

Office Scenario

6.1 Description

The experiment lasted for 19 days in November 2008. 44 Pocket Mobile Trace Recorders (PMTRs) were distributed to faculty members, PhD students, and technical staff. These people work in offices and laboratories located in a three-floor building, roughly 200x100 m large and take lunches or coffee breaks in a nearby cafeteria.

Recorded data was collected at the end of the experiment. Symmetric contacts, that is contacts recorded by both devices approximately at the same time, were kept for analysis; unidirectional contact records were discarded. This resulted in a collection of 11895 contacts between 44 PMTRs.

Reference:https://crawdad.org/unimi/pmtr/20081201/
Available at:https://crawdad.org/unimi/pmtr/20081201/

6.2 Trace Analysis

The figure 6.1 depicts the number of contacts corresponding each node. In X axis all 44 nodes are displayed and in Y axis the corresponding number of contacts are depicted.

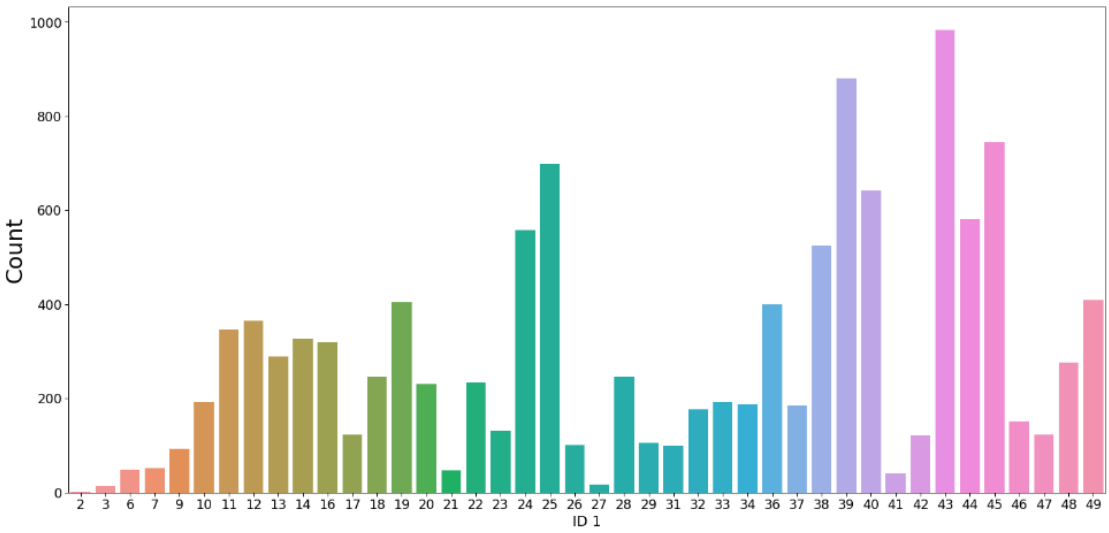

Figure 6.1: Contact Count

The figure 6.2 depicts the contact distribution with the time. As expected during the day time there are more contacts than the night time. Additionally, during the weekends there are no contacts recorded. Because of battery issues some nodes stop recording after 10

days. Therefore for the scenario only the first 7 days are considered.

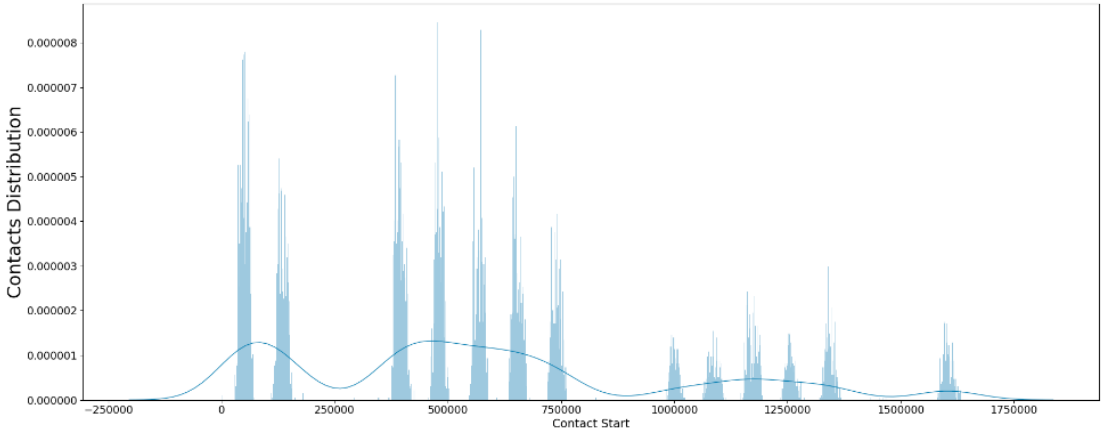

Figure 6.2: Contact Distribution

6.3 Scenario

By using the above mentioned trace the following scenario was developed. The messages are generated by the office workers.

In the table the type of messages generated and the size of the packet and the time to live (TTL) is also mentioned. Additionally for this scenario a cache size of 100 MB is used.

Office Workers
Images and videos Whatsapp – 50 KB– 30 min **Messages** Text Messages - 20 min Website Links - 2 hrs Special Events - 1 hr Location Information - 30 min Organizational Information – 120 min
Cache Size : 100 MB

Figure 6.3: Types of Messages

Some information about the simulation:

- Nodes - 49
- Time - 604,800 seconds (7 days)
- Packet Sizes - (0.2 kB - 50 kB)

- Time to Live - (20 min - 120 min)
- Cache - 100 MB

The data generation pattern is illustrated with the figure 6.4. In weekdays around 7am the packet generation begins and gradually increases with the time. During the breakfast and the lunch small number of packets are generated. The office workers are expect to generate more packets in the evening and increases the generation until the midnight. In weekends small number of packet are generated only during the day time.

The figure 6.4 shows the traffic generation frequency intervals for higher traffic and lower traffic scenarios separately. According to these generation intervals a value is selected randomly as the packet generation interval. If the generation interval is small, traffic is generated more often and if the generation interval is large, traffic is generated more sparsely.

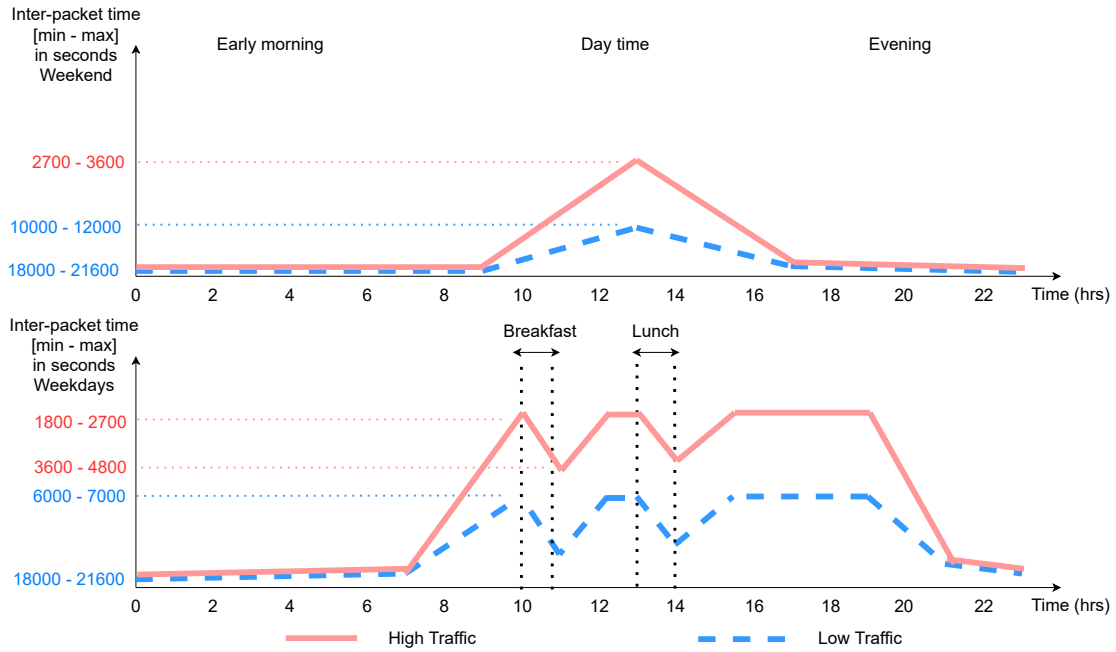

Figure 6.4: Packet Generation

- Number of packets with higher traffic- 4414
- Number of packets with lower traffic - 2360

The figure 6.5 shows the results obtain for this scenario with different forwarding protocols with high traffic and low traffic. In figure 6.6 the obtained delivery ratios are compared graphically and the table 6.1 illustrate the performance ranking of the used protocol in terms of delivery ratios.

Furthermore, figure 6.7 depicts the simulation statistics in OOTB with Epidemic routing protocol.

Parameter	Epidemic		RRS		Keetchi		Optmum Delay	
	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic	High Traffic	Low Traffic
Delivery Ratio	0.4976689316723 3	0.5294500774538 8	0.3112023405058 5	0.38332629207 154	0.0387457531143 83	0.0645067596 11322	0.53829747074 368	0.552202154 62611
Delivery Delay (s)	153114.09773759	144223.48193681	194828.20441163	181297.744087 35	37342.588760716	46788.467125 206	141269.553528 99	138065.2883 5478
All data sent (bytes)	11776355451	5264258825	19479580955	19965634533	2838968414	2637855547	2974700673	1660090253
Average Hops	3.1793279350691	3.0923296871363	14.085549658832	18.9647318148 42	10.405553525758	12.735434574 976	3.50056102948 91	3.508057189 3081
Average Neighbour Size	0.24296822697333		0.24296822697333		0.24296822697333		0.24296822697333	
Average Contact Duration (s)	1217.5307317073		1217.5307317073		1217.5307317073		1217.5307317073	
Total Contact Count	3075		3075		3075		3075	

Figure 6.5: Office Scenario Results

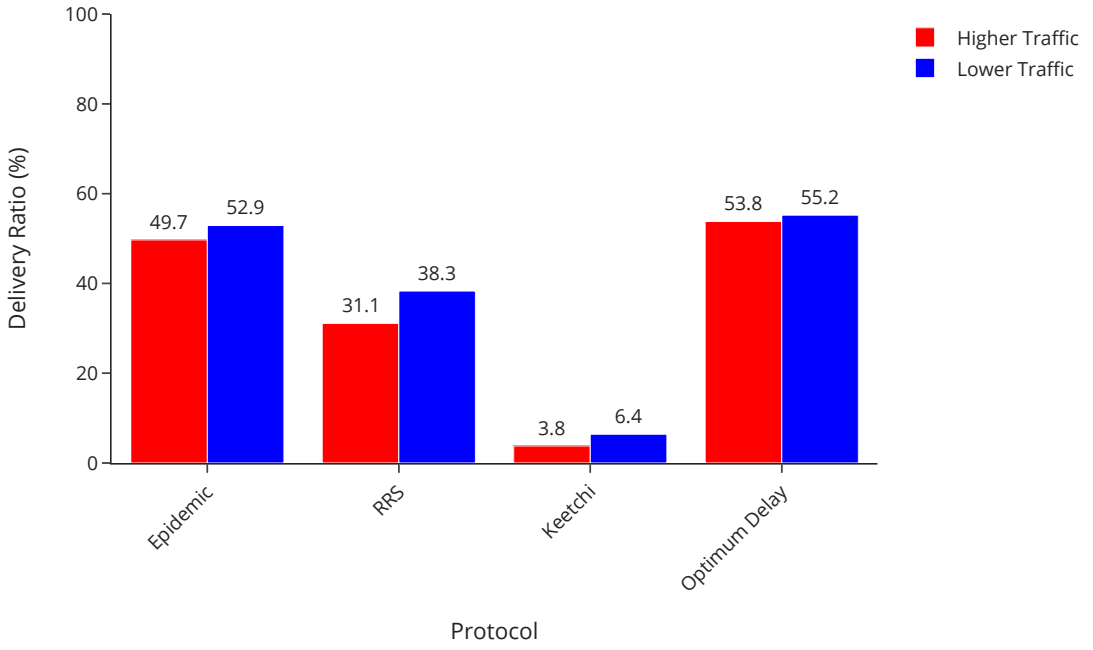

Figure 6.6: Delivery Ratio Comparison

Simulation Run Statistics

Start Wall Clock Time - 2021-01-26 11:37:44

Simulation Run Wall Clock Time - 702.687 seconds

Simulated Time - 604,800.0 seconds

Total Events - 40,205,734 events

Events per Wall Clock Second - 240,840.0 events

Simulation Seconds per Wall Clock Second - 4,773.95 seconds

Events per Simulation Second - 50.4489 events

Total Messages Created - 34,381,781 messages

Results Parsing Wall Clock Time - 548.2468018531799 seconds

Total Wall Clock Time - 1,250.9338018531798 seconds

Peak Disk Space Used - 7,877,059,731 bytes

Peak RAM Used (Simulation) - 2,339,557,376 bytes

Peak RAM Used (Results Parsing) - 3,782,098,944 bytes

Configuration file - omnetpp.ini

Configuration - Config Benchmark-07-Office-Scenario

Figure 6.7: Simulation Statistics with Epidemic (High Traffic)

Ranking	High Traffic	Low Traffic
1	Optimum Delay	Optimum Delay
2	Epidemic	Epidemic
3	RRS	RRS
4	Keetchi	Keetchi

Table 6.1: Delivery Ratio Ranking of Protocols

CHAPTER 7

Comparison

7.1 Scenario Comparison

The table 7.1 summarize all above mentioned scenarios and their high traffic and low traffic cases.

Details							High Traffic		Low Traffic	
Scenario	Nodes	Sim. Time	Contacts/ GPS	Symmetric	Contacts	Environment	Wall Clock time for Epidemic	Total Packets	Wall Clock time for Epidemic	Total Packets
Taxi	500	604,800 s	GPS	Yes	1,301,887	90 * 70 km	82.2 hrs	105,299	97.3 hrs	18,546
Typhoon	3600	200,000 s	GPS	Yes	1,136	75 * 88 km	36.2 hrs	12,566		
Conference	98	250,000 s	Contact	No	10,054	Inside a Hotel	70 min	9,103	50 min	3,837
University	54	604,800 s	Contact	No	766	Not Available	18 min	3,317	13 min	1,738
Roller Skate	62	10,800 s	Contact	Yes	21,153	30 km tour	2 min	1,514	1 min	743
Office	49	604,800 s	Contact	Yes	3,075	200 * 100 m (3-floor building)	20 min	4,414	14 min	2,360

Table 7.1: Scenario Comparison

The figure 7.1 depicts the obtained delivery ratios for each protocol in high traffic configuration and the figure 7.2 illustrate the results with low traffic configuration .

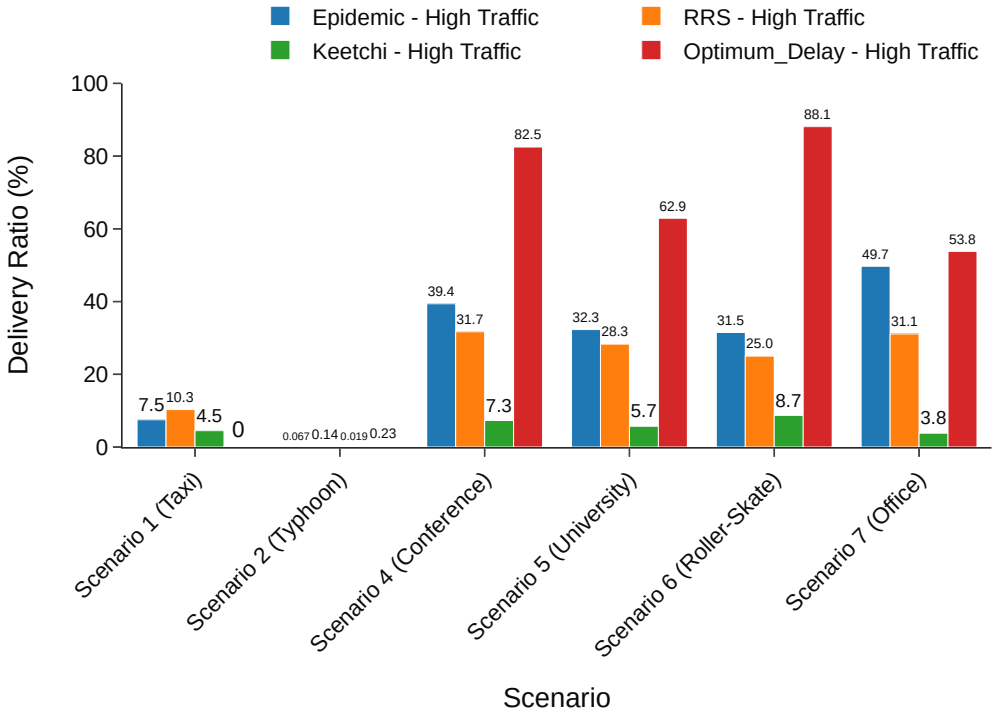

Figure 7.1: Scenario Comparison with High Traffic

The table 7.2 depicts the best and worst performing forwarding protocols for each scenario in terms of delivery ratios.

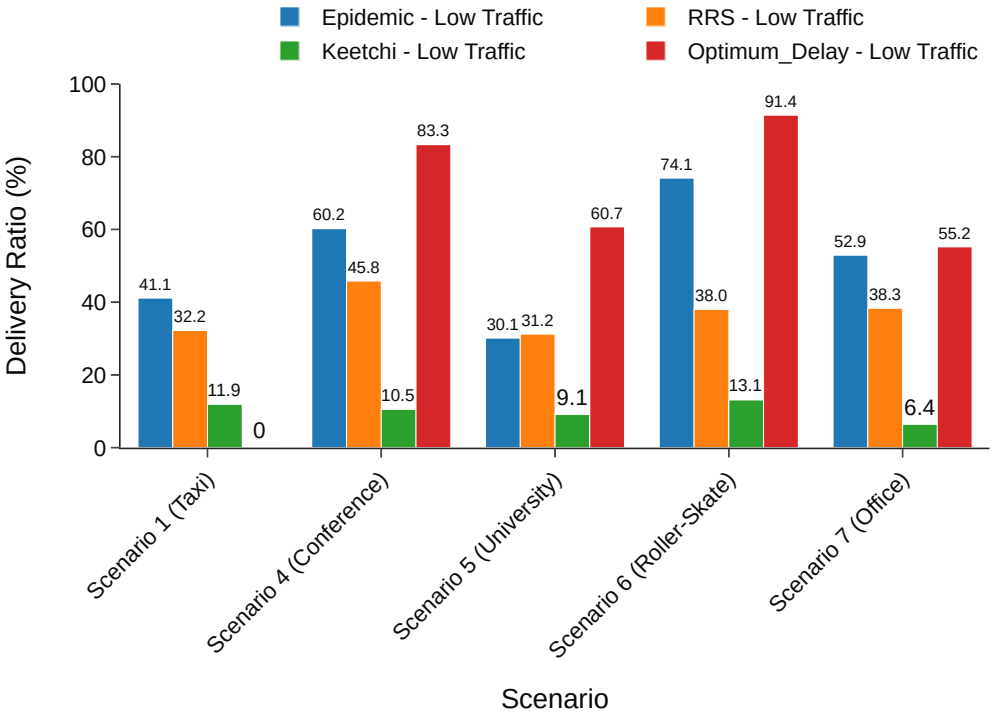

Figure 7.2: Scenario Comparison with Low Traffic

Scenario	Traffic	Rank			
		1	2	3	4
Taxi Scenario	High	RRS	Epidemic	Keetchi	-
	Low	Epidemic	RRS	Keetchi	-
Typhoon Scenario	Trace driven	Opt.Delay	RRS	Epidemic	Keetchi
Conference Scenario	High	Opt.Delay	Epidemic	RRS	Keetchi
	Low	Opt.Delay	Epidemic	RRS	Keetchi
University Scenario	High	Opt.Delay	Epidemic	RRS	Keetchi
	Low	Opt.Delay	RRS	Epidemic	Keetchi
Roller Skate Scenario	High	Opt.Delay	Epidemic	RRS	Keetchi
	Low	Opt.Delay	Epidemic	RRS	Keetchi
Office Scenario	High	Opt.Delay	Epidemic	RRS	Keetchi
	Low	Opt.Delay	Epidemic	RRS	Keetchi

Table 7.2: Scenario Ranking with Delivery Ratio