Congestion Control Strategies on Integrated Routing Protocol for the Opportunistic Network: A Comparative Study and Performance Analysis

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ABSTRACT
This work presents the incorporating of congestion control on the integrated routing protocol of the opportunistic networks. Pre-emptive congestion control strategies were incorporated into the integrated routing protocol. Results showed that the duplication avoidance improved the integrated routing protocol because it reduced the packet loss and improved the delivery probability. Duplication avoidance reduced the packet loss by 58% and improved the delivery probability by 4% at the end of the simulation time when compared with the delivery probability and packet loss of the integrated routing protocol without congestion control. The use of acknowledgement, buffer size advertisement, data centric method reduced the packet loss by 2.5%, 57% and 57% respectively but did not improve on the delivery probability significantly

General Terms
Opportunistic network, congestion control, ONE simulator

Keywords
Prophet routing protocol, epidemic routing protocol and integrated routing protocol.

1. INTRODUCTION
The opportunistic network is an autonomous connection of users that communicate over a relatively bandwidth constrained wireless network [1]. It is a delay tolerant network (DTN) and it consists of nodes which are electronic devices that are attached to a network and are capable of sending, receiving or forwarding information over communication channel [2]. The basic features of the opportunistic networks are: It has wirelessly connected nodes which can be fixed or mobile, A complete path between two nodes aspiring to communicate does not exist, It does not have a fixed communication range, Its routes are dynamically built as any node can opportunistically be used as next hop provided it is likely to bring the message closer to the final destination, Network topology is also flexible as it can change at any time amongst others [3], [4], [5]. The two main routing techniques for opportunistic networks are the context-aware (an example is the Prophet routing protocol) and the context-oblivious (an example is the Epidemic routing protocol). Prophet' is able to learn automatically from the past communications opportunities determined by user's mobility pattern and use context information in the future to route messages. This self-learning feature is absent in 'Epidemic' as it floods the message all over the network, thereby causing congestion and creating high overhead. Epidemic is the only solution when context information about the users is not available

Epidemic is better (in terms of message delay and delivery probability) in absence of context information while 'prophet' gives better result with context information available [6], [7]. It is not certain that a node with a higher metric will be encountered within reasonable time. It may be possible that a destination is new and context information about that destination is not spread in network. To address these problems, the integrated routing approach uses context data as soon as it is available and falls back to dissemination-based routing when context information is not available. It distributes copies of messages to all its neighbors (same as flooding-based techniques), after a configurable time, when nodes have not received any context information about the destination of message. However, it did not consider congestion control and resource utilization which would have improved its performance. [5].

The authors in [8] surveyed the processes of delay tolerant networks congestion control and organised a taxonomy that helped in mapping and comparing the existing DTN congestion control mechanism. They deduced that "there is no universal congestion control mechanism that will be applicable to all DTN scenarios and applications". In the work of [9], integrated buffer management strategy (CIM) was proposed and evaluated using ONE simulator with a view to reducing congestion. But lower delivery ratio and higher overhead was recorded as compared to the spray-and-wait model. Authors in [10] presented a model to help designers carry out fair comparisons among protocols. But the model was not robust because it did not consider more routing protocols. [11] Presented a buffer management strategy to avoid head-of-line blocking in the first-in-first-out case and showed that the proposed strategy reduced the degradation of average delivery delay performance [11].

The opportunistic network environment (ONE) simulator was developed by [12]. It is a customizable java-based simulator targeted for research in DTN routing and application protocol .The rest of the paper is organized as: Section 2 describes congestion in opportunistic network. Section 3 gives the methodology adopted with the simulation setup. Section 4 presents the result obtained and comparison of the congestion control strategies. Section 5 concludes the research.

2. CONGESTION IN OPPORTUNISTIC NETWORKS
Opportunistic Network is characterized by sparse connectivity, fault tolerance and forwarding through mobility. Hence, many routing protocols [7], [13], [14], [15], [16] adopt flooding based schemes to deal with the problem of network partitioning and unpredictability in connections in order to increase the message delivery. Node receives packets, stores them in their buffer, carry them when moving and pass them to other nodes when they meet each other. The excessive multi-copies spraying in the network cause serious network congestion by exhausting the nodes, there by influencing the

performance of transmission [9]. In opportunistic networks, no end-to-end connection is established and therefore congestion cannot be detected and controlled by a feedback loop [17], [18].

With an uncontrolled eviction policy there is a potential risk that all replicated copies of the data may be evicted before all destinations have been reached, hence decreasing the delivery ratio [17]. Congestion occurs when a node's buffer becomes saturated. Lack of end-to end path between the source and the destination coupled with limited resources and high delays effect TCP/IP protocols in opportunistic environments. There is no propagation in the network making many Internet protocols (such as TCP) designed to assume quick return of acknowledgement and data susceptible to failure [19] The challenge is how to avoid congestion without the feedback loop, using just local information at nodes. Avoiding congestion can be done by pre-emptive eviction of data items from the buffers of the nodes. This could be done in the following ways:

i. Buffer eviction using acknowledgement

The use of acknowledgement in opportunistic network differs from that of legacy network. In the Internet, TCP acknowledgements are used to show that the message has reached its destination hence, the message does not need to be retransmitted and nodes will discard the message from their buffer. But this is not possible in opportunistic networks as there is no end-to-end connectivity. To use acknowledgement in opportunistic network, Time-to-live that is longer than the message must be attached, else, a copy of the message can still live on the network. The advantage with acknowledgement is that nodes are sure that the message has been delivered to the destination before the message is evicted from the buffer. A disadvantage is that it takes time for an acknowledgement to disseminate in the network. Acknowledgements also need time-to-live (TTL) to avoid the packets from lingering in the network [17].

ii. Buffer size advertisement

Congestion collapse (congestion caused by aggregated undelivered replicated packet that waste bandwidth) can be avoided by nodes sharing their buffer utilization statistics with neighboring nodes. With those statistics, a node can estimate the congestion level at neighboring nodes. By advertising their free buffers, the neighboring nodes can take decision on what to forward and how much to transfer, making it possible to avoid overloading the node and to prioritize message in order to use the buffer space as efficiently as possible. This method of congestion avoidance may increase the delivery time [17].

iii. Data-centric node congestion avoidance

In the data-centric strategy, messages are forwarded based on the interest in the data. Using this principle in opportunistic networks, it is assumed that a node is more likely to provide buffer space for data items that are of interest to the node itself. It is also assumed that forwarding nodes keep data that they are interested in, which makes the interested forwarding node to become the new source [17]. Nodes choose to evict data that is of little interest to the nodes in the network, as few nodes will request for that data. Nodes can also decide to evict data that is of high interest by assuming that other nodes probably have the data, since it will be frequently requested for and shared. The disadvantage of this strategy is that there is an increase in storage of data items that will never be forwarded or have already reached all nodes interested in the data [17]. Either they are data items that no node is interested in, or data items that have been replicated many times. These data item become stale and consume buffer space, which could have been used to forward other data item.

iv. Duplication Avoidance

In this strategy, a node keeps only messages it does not have in its buffer. That is, no duplication of messages. When a node comes into communication range with other nodes, it receives a message and checks if it has the same message in its buffer, if it has the message; it then deletes the message in order to avoid duplication. This method avoids unnecessary wastage of buffer space by ensuring that no same copies of messages is kept in the buffer.

3. METHODOLOGY

The methodology adopted in this research is as follows:

- Modeling of the opportunistic network using the integrated routing protocol.
- Incorporation of the congestion control strategies into the ONE simulator.
- Simulation using the ONE simulator

3.1 Modeling the Opportunistic Network using the integrated routing protocol.

The integrated routing protocol was used to model the opportunistic network where every node maintains a delivery probability metric.

The metric is updated whenever a node meets with other nodes using equations (1) to (3) of [20]. When node x meets node y, the delivery probability of node x for y is updated by:

$$P'_{xy} = P_{xy} + (1+P_{xy})\, P_0 \qquad (1)$$

Where P_0 is an initial probability (P_0 ranges between 0 and 1), P'_{xy} is the current delivery probability of node x for y and P_{xy} is former delivery probability of node x for y. When node x does not meet with node y for some predefined time, the delivery probability decreases by:

$$P'_{xy} = \gamma^k P_{xy} \qquad (2)$$

Where γ is the aging factor (γ < 1), and k is the number of time units since the last update. When node x receives node y's delivery probabilities, node x may compute the transitive delivery probability through y to z by:

$$P'_{XZ} = P_{XZ} + (1 + P_{XZ})P_{xy}\ P_{YZ}\beta \qquad (3)$$

Where β is a design parameter for the impact of transitivity. β ∈ [0, 1].

The values of P_0, γ and β used for this research are 0.75, 0.98 and 0.25 respectively.

3.2 Incorporating the Congestion Control Strategies

The congestion strategies that were coded in java and incorporated into the ONE simulator are:

i. Buffer eviction using acknowledgement

Nodes were made to delete copies of messages from their buffers once they receive an acknowledgement that the message has reached its destination. A TTL of 300 seconds was assigned to the messages. The use of Acknowledgement as the means of congestion control was called into the scenario settings of the ONE using the following Code:

Scenario.name = Baseerah_Acknowledgement

ii. Buffer size advertisement

Nodes advertise their buffer size so that a sending does not send what the receiving node cannot carry. The use of buffer size advertisement was called into the scenario setting of the ONE using the following Code:

Scenario.name = Baseerah_Advertisement

iii. Data-centric node congestion avoidance

Nodes receive only messages they are interested in, or messages they think it will have high demand from other nodes. The use of Data-centric node congestion avoidance was called into the scenario setting of the ONE using the following Code:

Scenario.name = Baseerah_DataCentric

iv. Duplication Avoidance

Here, before a node receives a message from a sending node it must check its buffer to make sure it does not have the message in order not to duplicate the message. The use of Duplication Avoidance was called into the scenario setting of the ONE using the following Code:

Scenario.name = Baseerah_DuplicationAvoidanc

3.3 Simulation using ONE

A part of the Helsinki downtown area as depicted in Figure 1 was used (4500 X 3400m). Communication between modern mobile phones and similar devices (such as, personal digital aid) was assumed. Devices have up to 20MB of free RAM for buffering messages. Users travel on foot, in cars or trams. Some paths to the parks, shopping malls and trams route have been added. Simulation was run using 100 nodes. Mobile nodes have different speeds and pause times.

Figure 1: An Overview of the Helsinki Simulation Area

Pedestrians move at random speeds of 0.5 to 1.5m/s, taking a pause time between 0 to 120s. Cars are optional, when present; they make 20% of node count, moving at a speed of 10 to 50km/h, with a pause time of 0 to 120s. Trams run at a speed of 7 to 10m/s, pausing for 10 to 30s at each configured stop. An assumption of 10m range, 2Mbits Bluetooth and a low power use of 802.11bWLAN (30m range, 4.5Mbits). Mobile users generate messages on an average of once per hour per node. Messages lifetime of 3, 6 and 12 hours were used. The message size used was uniformly distributed between 100kb (test message) and 2MB (digital photo). Part or the scenario setting is shown as:

Scenario.name = Baseerah_Integrated

Scenario.simulateConnections = true

Scenario.updateInterval = 1.0

Scenario.endTime = 43200

Scenario.nrofHostGroups = 1

btInterface.type = SimpleBroadcastInterface

btInterface.transmitSpeed = 250k

btInterface.transmitRange = 10

highspeedInterface.type = SimpleBroadcastInterface

highspeedInterface.transmitSpeed = 10M

highspeedInterface.transmitRange = 1000

Group.movementModel = RandomWaypoint

Group.router = [ProphetRouter;EpidemicRouter;] #[Integrated]

ProphetRouter.secondsInTimeUnit = 1

Group.bufferSize = 10M

Group.nrofInterfaces = 1

Group.interface1 = btInterface

Figure 2 shows the integrated routing simulation carried out on Helsinki map where nodes follow a predefined path and communicates in a transitive manner.

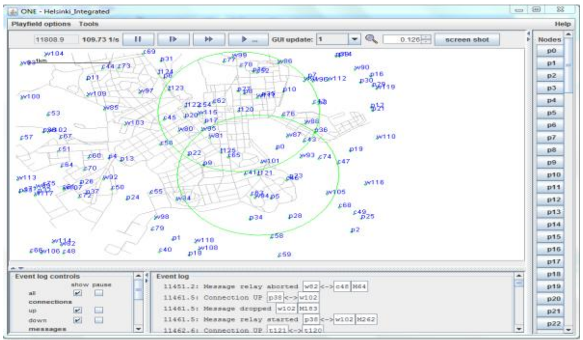

Figure 2: An Overview of the Helsinki Integrated Routing Simulation

4. RESULT AND DISCUSSIONS

The results obtained from the application of the four congestion control strategies into the integrated routing protocol on the Helsinki simulation area are shows in Tables 1 and 2, where PL and DP represent packet loss and delivery probability respectively. Table 1 shows the result obtained for the integrated routing protocol without congestion control, while Table 2 shows the result obtained from the different congestion control strategies.

Table1: Integrated Routing Simulation without Congestion Control for Helsinki Region

Integrated Routing		
Sim time (s)	PL	DP
0	0	0
1000	0	0.078

2000	0	0.099
3000	6	0.082
4000	25	0.082
5000	36	0.099
6000	48	0.102
8000	74	0.103
10000	84	0.102
12000	119	0.101
14000	155	0.103
16000	180	0.103
18000	192	0.103
20000	215	0.104
22000	245	0.103
24000	280	0.104
26000	320	0.105
28000	385	0.106
30000	420	0.106
32000	452	0.104
34000	485	0.104
36000	519	0.103
38000	564	0.103
40000	602	0.104
42000	648	0.1052
43200	670	0.1048

It can be deduced from Table 2 that the duplication avoidance performs better with a final PL of 283 and DP of 10.9% as compared to Table 1 without congestion control strategy having a PL and DP 670 and 10.48% respectively. The use of acknowledgement, buffer size advertisement and data centric method have PL of 653, 286 and 290 respectively and DP of 0.105, 0.103 and 0.105 respectively. The graphical representation of the improved integrated routing with congestion control as compared with that of the integrated routing protocol without congestion control is shown in Figures 3 and 4. Figure 3 shows the variation of packet loss with time while Figure 4 shows the variation of delivery probability with time. Figures 3 and 4 were generated using the Matlab (Matlab 2013Rb) script.

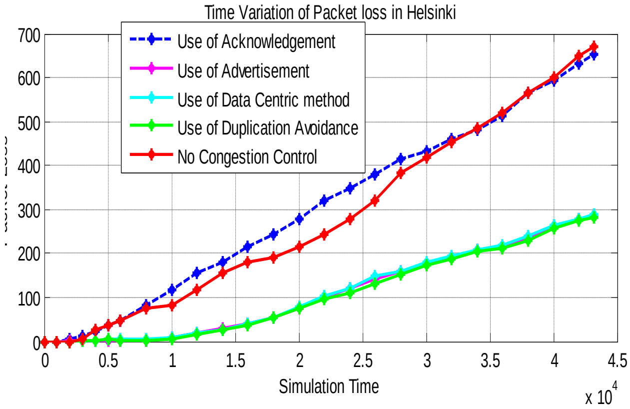

Figure 3: Variation of Packet Loss with Time for Helsinki Region.

Figure 3 shows that buffer size advertisement, data centric method and the avoidance of duplication reduced the packet as compared to the integrated routing protocol without congestion control. The use of acknowledgement reduced the packet loss only towards the end of the simulation time.

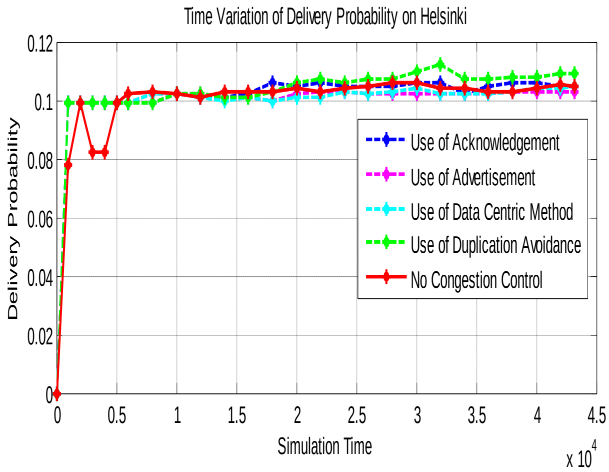

Figure 4: Variation of Delivery Probability with Time for Helsinki Region

Table 2: Improved Integrated Routing With Congestion Control for Helsinki Region

	Acknowledgement		**Advertisement**		**Data Centric**		**Duplication Avoid**	
Sim time (s)	PL	DP	PL	DP	PL	DP	PL	DL
0	0	0	0	0	0	0	0	0
1000	0	0.099	0	0.099	0	0.099	0	0.099
2000	5	0.099	2	0.099	0	0.099	0	0.099
3000	11	0.099	2	0.099	2	0.099	1	0.099
4000	24	0.099	2	0.099	3	0.099	2	0.099
5000	36	0.099	2	0.099	5	0.099	4	0.099

6000	48	0.099	2	0.099	5	0.099	3	0.099
8000	84	0.099	3	0.102	6	0.102	3	0.099
10000	117	0.102	9	0.102	8	0.102	7	0.102
12000	155	0.101	19	0.102	18	0.101	15	0.102
14000	180	0.101	30	0.101	28	0.1	25	0.101
16000	216	0.102	42	0.101	40	0.101	38	0.101
18000	242	0.106	54	0.1	53	0.1	53	0.103
20000	280	0.105	76	0.102	78	0.101	74	0.106
22000	320	0.106	101	0.103	105	0.101	98	0.107
24000	350	0.105	120	0.103	122	0.103	111	0.106
26000	380	0.105	143	0.102	148	0.102	130	0.107
28000	415	0.105	158	0.102	160	0.103	152	0.107
30000	432	0.106	178	0.102	179	0.104	172	0.11
32000	462	0.106	191	0.102	195	0.102	187	0.112
34000	480	0.102	210	0.102	208	0.102	205	0.107
36000	513	0.105	217	0.102	220	0.102	213	0.107
38000	564	0.106	237	0.103	240	0.103	231	0.108
40000	594	0.106	261	0.103	265	0.104	256	0.108
42000	632	0.105	279	0.103	280	0.104	275	0.109
43200	653	0.105	286	0.103	290	0.105	283	0.109

From Figure 4, duplication avoidance outperformed other strategies as it had higher delivery probability almost throughout the simulation time. In general, congestion control using buffer size advertisement and the data centric methods reduced the number of packet loss but did not improve the delivery probability of the messages significantly. This is because there is no end-to-end connection in an opportunistic network. Hence, nodes are using any slight opportunity available to send messages. These forms of congestion control prevent nodes from accepting all messages, (due to buffer size or based on interest), as a result reducing forwarding opportunity (forwarding probability) and consequently the delivery probability. The use of acknowledgement did not improve the delivery probability because of the absence of end-to-end connectivity in an opportunistic network. The acknowledgement is either not received at all or not received in reasonable time. Hence, nodes still keep the messages in their buffer long after it has reached its destination. This is not an effective way of preventing congestion in an opportunistic network. The duplication avoidance reduced the number of packet loss as well as improved the delivery probability. This is because this method did not block any chance of forwarding messages except those messages that already existed in the node. Hence it did not decrease forwarding probability and it saved buffer space by preventing duplication. This resulted in an improved delivery probability.

Duplication avoidance improved the integrated routing better because it reduced the packet loss and improved the delivery probability. Duplication avoidance reduced the packet loss to 283 (58% improvement) and improved the delivery probability to 0.109 (4%) at the end of the simulation time. The use of acknowledgement, buffer size advertisement, data centric method reduced the packet loss to 653 (2.5% improvement), 286 (57% improvement) and 290 (57% improvement) respectively but did not improve on the delivery probability significantly. Their delivery probabilities are 0.105, 0.103 and 0.105 respectively at the end of the simulation time. The delivery probability and packet loss of the integrated routing protocol without congestion control are .1048 and 670 respectively.

5. CONCLUSION

This work presents the application of congestion control on the integrated routing protocol. Four pre-emptive congestion control strategies (acknowledgement, buffer size advertisement, data centric method and the avoidance of duplication) were used. These results showed that, duplication avoidance improved the performance of the integrated routing protocol better (in terms of delivery probability and packet loss) than other congestion control strategies.

Security measures can be considered in the integrated routing of the opportunistic networks since malicious devices are likely to join the opportunistic network because of lack of initial authentication. All the congestion control strategies can be integrated as a hybrid congestion control strategy and used to further improve the performance of the integrated routing protocol. Extensive experimental setup (like the vehicular mobility model) can be used to evaluate the performance of the integrated routing protocol.

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