Factor Effects for Routing in a Delay-Tolerant Wireless Sensor Network for Lake Environment Monitoring

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Abstract. Delay-tolerant wireless sensor networks (DTWSN) is a promising tool to facilitate communication in disruptive and challenged sensor network environments not usually catered by traditional systems. In this paper, DTWSN application to a real-life lake scenario is considered with the description of the routing problem and proposed solution. Opportunistic Network Environment (ONE) simulator was utilized to determine the performance of First Contact, Epidemic and Spray and Wait routing protocols on the map-based mobility model of the lake. Factors considered are the number of nodes, bit rate and ferry speed. Analyses of delivery probability, latency and overhead ratio as well as buffer time and hop count as metrics of performance evaluation against the protocols are done using JMP software. Results revealed that Spray and wait outperforms the other protocols for the given scenario.

Keywords: Wireless sensor networks · Delay tolerant networks
DTN routing · ONE simulator · JMP software

1 Introduction

The challenges and required mechanisms for wireless sensor networks (WSN) [1, 2] had put forward a vast opportunity for innovation becoming evident in the market today with the increasing availability of smart sensor products for various deployments. Beyond its conventional uses, WSN deployment found its way in forests [3], inhospitable terrain such as volcanoes, lakes and remote places inaccessible for any wired service because of the limited or total absence of network infrastructures. The absence of a stable path and irregularity of radio propagation in this type of environment contributes to delays and loss of signal. Research activities are active in the development of delay-tolerant communication networks that will operate in this kind of environment [4] and the interoperability of such networks with the conventional TCP/IP network is provided by an overlay architecture known as delay-tolerant networking (DTN) described in RFC 4838 [13].

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Sensor networks that have features of both WSN and DTN are termed as delay-tolerant wireless sensor networks (DTWSN). It is a network deployment of sensor nodes where there are disruptions in the network connectivity because connection paths among nodes suffer disconnections; there are relatively long and variable delays, encounters high losses in the communication link and high error rate. Some real-world applications of DTN to sensor networks are described in [8] that include wildlife tracking, village communication network [5], social-based mobile networks [6] and disaster response ad-hoc networks [7]. It was envisioned by the interest group, DTNRG, that delay tolerant networks R & D activities and implementations will soon provide communication services to undeveloped parts of the world where there is scarce communication facility/infrastructure. A survey of projects in DTN applied to sensor networks is found in DTN-The State of the Art published by N4C [8].

This paper provides the following contributions: (1) describe a scenario for a scheduled-opportunistic routing in a delay-tolerant wireless sensor network for Lake Environment monitoring, (2) perform simulations and analyze the performance evaluation of three routing protocols used in a delay tolerant network as applied to the lake scenario. The scope is limited to the performance evaluation only of three routing protocols used in a delay tolerant network applied to the mobility model of the cited scenario. The radio performance of the delay-tolerant WSN and hardware design is part of future work.

The paper is organized as follows: Sect. 2 discusses the motivating scenario and related work. Section 3 provides an overview of delay-tolerant wireless sensor networks and routing protocols as well as describes the routing in a lake environment. Section 4 describes the simulation and design of experiment used. Section 5 presents the results. Finally, Sect. 6 concludes the paper.

2 Motivating Scenario and Related Work

A lake seventeen square kilometers in area is considered as use-case for delay-tolerant WSN deployment for environment monitoring. Lake Buhi in Camarines Sur, Philippines is known to the world as the home of the world's smallest fish, the Sinarapan (*Mistichthys luzonensis*) or locally known in the area as the "tabyos" which is previously under the threat of near extinction caused by overfishing, low water quality and abusive use of the lake environment (Fig. 1). The local government has managed to issue ordinances for the protection of the endemic fish by designating a portion of the lake as a fish sanctuary and to mitigate other problems such as the recurring tilapia "fishkill" that results to loss of income thereby affecting the livelihood of the people in the area. Aside from implementing schemes for the management and biodiversity enhancement of the lake environment that includes removal of excessive fish cages and fish repopulation strategies, a policy framework [11] was also proposed to meet the need for regular, close monitoring of the water quality of the lake especially the fish sanctuary. Compared to the manual water quality detecting methods that takes a long time to gather data, deploying a monitoring system based on the concepts of DTWSN (delay-tolerant wireless sensor networks) would present significant advantages such as convenience in the monitoring

Fig. 1. Lake Buhi in Buhi, Camarines Sur, Philippines with Mt. Asog at the background (Left) and a typical motorized ferry boat (Right) that cruises its water.

and faster collection of a variety of water parameters, a higher detection accuracy and enhanced data management of the monitoring system [9].

However, the design and set-up of the sensor network used in conventional indoor or short-range monitoring is not suited for remote large-area outdoor environment settings like forests and lakes because of the obvious difference in the landscape and circumstances. Relevant works [9, 10] developed hardware and software components of monitoring systems specifically addressing the lake environment and were consisting of data monitoring nodes/modules, data base station and remote monitoring center. Zigbee technology and GPRS/GSM modules were utilized to connect to the data server. The one used in Lake Palikpikan in Laguna made use of a novel sensor system with aerator that measures sensor data at two different depths over a period of one year. The project utilized UAV imaging over the lake to quantify fish cage density, water hyacinth coverage and disaster damage. It also utilized crowd-sourced participatory sensing by lake stakeholders through smartphone applications via cellular network. In this paper, delay-tolerant WSN for lake monitoring was explored using public ferry boats as DTN agents. This is similar in concept to the work in [12] which tackled ferry-assisted data-gathering. Since public ferry boats ideally travel on schedules and follow specific routes but may incur delays in actual travel time and may divert from usual routes, then DTN concepts can be utilized to collect data from the sensor nodes as the boats travel across the target coverage area and then route the data to a server. Mobile nodes may also be utilized rendering a combined scheduled-opportunistic approach for the target application.

3 Delay-Tolerant Wireless Sensor Networks and the Routing Problem

RFC 4838 and the Bundle protocol (RFC 5050) [13, 14] describe the DTN architecture, how it operates as an overlay above the transport layers of the networks it interconnects with, and the key service it offers. Between the application layer and the transport layer in the DTN protocol stack is another layer called the bundle layer. It implements the store-and-forward message switching mechanism. “Bundles” are application data that has been processed in the bundle layer and passed to the transport layer. Network disconnections are overcome by the so-called custody transfers that provide the end-to-end reliability across the DTN. The said layer hides the disconnection and delay from the application layer [4]. The nodes in a DTN have the support for longer storage and custody transfers (see Fig. 2). These features grant the sensor nodes the ability to exploit scheduled, predicted and opportunistic connectivity. The system that has this ability can operate under intermittent connections.

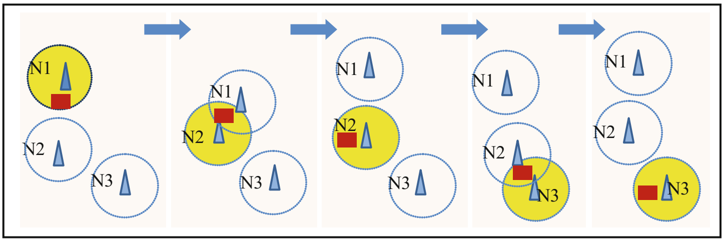


Fig. 2. Custody transfer and the routing in DTN leverages on its built-in store-and-forward mechanism. Initially, message bundle (B) is stored at node N1 then when N1 is in contact with N2, the bundle will be forwarded to N2 which will have custody of the bundle until it makes contact with N3, the final destination of the message.

The forwarding scheme that employs node to node retransmission achieves end-to-end reliability, owing to DTN's built-in mechanism that prevents data loss and corruption. Researchers argued that the existing communication protocols independently developed for WSN and DTN may not be suitable for DTWSN because most of the existing WSN assumes always available data path and existing DTN designs on the other hand do not fully consider practical node energy, storage and computational capabilities [5].

In [15], an evaluation framework for DTN routing was proposed with emphasis on providing a trade-off between maximizing the delivery ratio and minimizing the overhead. It also discussed two broad categories of routing protocols under unicasting: routing without infrastructure assistance and routing with infrastructure assistance. The one considered in this study is classified under the latter, specifically routing scheme that uses mobile node relay where changes in movement play an important role in routing performance. A *mobility model* is therefore a requirement to imitate the movement pattern of the targeted real world applications in a relevant manner. The scope of the paper is limited to three routing protocols.

First Contact routing protocol dictates that the node forward messages to the first node it encounters along the way, this results in a "random walk" search for the destination node [15]. This is a technique where a node will transfer a single copy of the message to the first node it comes in contact with and it will continue until the message reaches the destination.

Epidemic routing [17], as one of the early proposed schemes that enable data delivery in intermittently connected mobile networks, is essentially a flooding protocol that replicates and propagates copies of a message to many mobile nodes within the network as well as retaining a copy of the message for a period of time. As its name suggests, a node replicates a message and forwards it in an infective manner to a susceptible one once contact happens due to their movement.

Spray and Wait [18] routing protocol is an improvement of the epidemic routing by putting a maximum limit on the number of copies of message the source node generates. It has two phases: the Spray phase is where M copies of messages are forwarded to M distinct nodes; while Wait phase is when the nodes encountered are not the destination node then must wait until direct transmission to the destination is possible. Both epidemic and spray and wait protocols assume no knowledge of network topology and nodes mobility.

In a typical lake scenario, several public ferry boats traverse the water based on schedules and planned routes. In effect, the combined use of ferries and sensor nodes deployed in the water essentially make contact opportunities for data transfer. The simplified network model is shown in Fig. 3. There can be two groups of sensor nodes; one is clustered with designated cluster head while the other group consists of stand-alone nodes directly communicating to the ferry/mobile data collector. All are buoyed sensor nodes and are assumed to be fixed in position but may tolerate changes in location due to air and water movement. It is further assumed that the nodes are DTN-enabled meaning they are capable of store-and-forward routing.

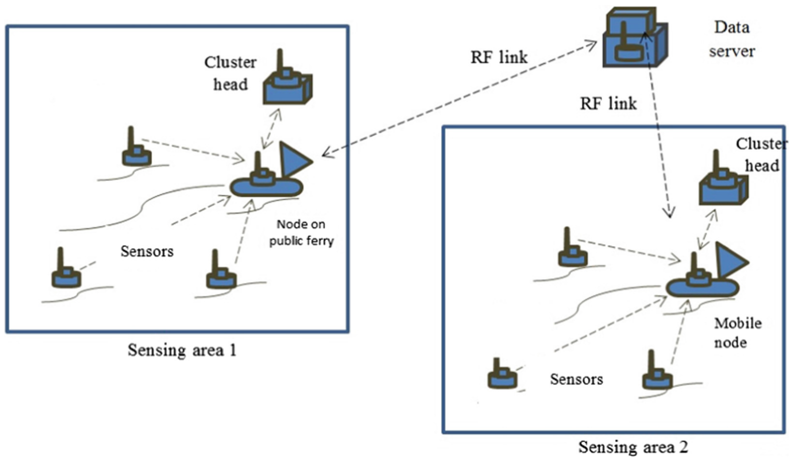


Fig. 3. The simplified network model shows the basic elements. The sensor data are collected as the ferry and mobile nodes move along its route in a scheduled-opportunistic manner.

The mobile node (or message ferry) also serves as the DTN router cum network coordinator and cluster head (in cases where the cluster head is offline) and is capable of store-carry-forward routing. In the event that the functionality of these nodes is compromised, the node needs to be able to delegate the responsibility of ensuring data flow to another suitable node in the network. As a network coordinator/cluster head, it performs the wake-up call to sleeping nodes and performs data aggregations. As the mobile node moves in close proximity to the field sensors, data is transferred to the mobile node for later forwarding to the server.

At the start of operation, the server located at the ferry terminal will initiate request order for data. It will search for active routers (F1, Mobile node) to act as network coordinators by means of a status report. Active routers then broadcast the packet to awaken the cluster heads (C1, C2, C3, C4) as well as the sensor nodes (N1, N2,…) which are in sleep mode most of the time. The nodes will measure the water parameters then sends data to the cluster head which perform data aggregation, stores the aggregated data for a period of time before forwarding to the ferry or mobile node upon contact. The nodes are capable of custody transfers and cooperative relay so that data will be passed from the distant node to the node in close proximity to the ferry. The area to be monitored is divided into clusters based on the assumed sensing range of the nodes (ferry) traversing that route. The schedule of data collection is assumed to be coinciding with that of the ferry boat travel schedule, in this case twice in the morning and twice in the afternoon with two ferry boats per routes with interval of two hours each. For each cluster of stationary sensor nodes, a node relaying algorithm will minimize transmission delay while the waiting delay between mobile ferries will be taken care of by the ferry route algorithm that assumes direct interactions between ferries. This proposed algorithm is just described here, the details of which will be provided in the future (Fig. 4).

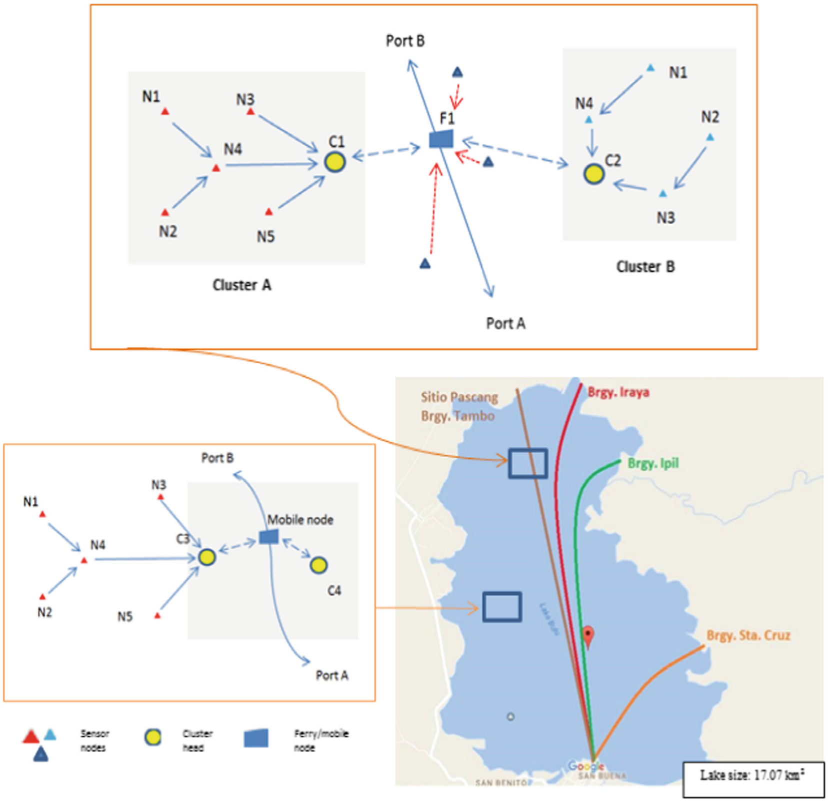


Fig. 4. Map of the ferry boat routes and the routing problem

4 Simulation and Design of Experiment

Simulation is essential in the study of WSN. There are a number of network simulators available for free downloads but there is one that is gaining popularity due to its support for DTN routing as well as mobility modeling and visualization. It is the Opportunistic Network Environment simulator or ONE simulator [16, 19] and for this study, version 1.4.1 was utilized. Previous works in [7, 12] used ONE simulator to simulate and analyze existing DTN Protocols.

4.1 Mobility Model

With the desire to emulate the movement pattern of the targeted real world applications and considering the application cited in this paper, a mobility model was derived for the lake monitoring sensor network. In the ONE simulator, map-based mobility model was selected to constrain the movement of the nodes to paths (routes) defined in the map data. The map data of the lake was obtained in WKT format using OpenJUMP [21], an open-source GIS program.

4.2 Performance Metrics

The parameters evaluated in the simulation are delivery probability, latency and overhead ratio. By using these metrics, the impact of the mobility model on the protocol performance was drawn from.

Delivery probability is the ratio of the number of messages that reaches the destination to the number of total messages generated and is an indicator of how reliable the network is in terms of message delivery.

Latency or delivery delay is the time it takes for a message to be delivered from the source to the destination. In a DTN system, a longer transmission delay is permissible but improving time of delivery will benefit the performance.

Overhead ratio is the number of messages replicated divided by the total messages in the network. The overhead ratio implies the use of network resources and buffer space due to the use of multiple copies of the same message to increase delivery chances.

Also considered in the results are *Hop count* which is the number of times the messages are exchanged between nodes before reaching the destination, and *Average buffer time* which is defined as the average time incurred by all messages that are delivered abandoned or stranded at the intermediate node buffers.

4.3 Factors

The factors considered in the simulation are: the number of nodes that vary from 12 to 40, data rate of the wireless interface used in the simulation is 802.11 or Wi-Fi that varies from 40 to 1375 kbps representing low-, medium-, to high-speed data rate, and ferry speed that typically varies from 0.5 to 3.5 m/s. The conduct of the experiments by network simulation had tried to model how these factors impact the performance of the protocol for the given scenario.

4.4 Simulation Parameters

The parameters used in the simulation are listed in Table 1. The complete set-up of the simulation environment is listed in a text-based configuration file that contains the parameters. Data resulting from the simulations were retrieved in the MessageStatReport text file generated by ONE Simulator.

Table 1. ONE simulation parameters adjusted in the settings for each set of runs.

Parameter	Value
Message size	500K–1 MB
Buffer size	50 M
Number of nodes	varied
Area (m^2)	3400 × 4500
Interface	802.11
Data rate	varied
Sensing range (m)	30–100
Ferry speed	varied
Protocol used	FirstContact, Epidemic, SprayAndWait

4.5 Design of Experiment and Performance Evaluation Using JMP Software

To help in the selection of inputs with which to compute the output of the ONE simulator experiment, Space Filling design was utilized. This is a design of experiment technique suitable for computer simulations because of the deterministic nature of the model. A goal of designed experiments on such model is to find a simpler approach that adequately predicts the system behavior over limited ranges of the factors [20]. The Fast Flexible Filling method was chosen because it is the only method that can accommodate categorical factors and constraints on the design space. The categorical factor refers to the type of protocols used in the simulation. To maximize the use of the collected data and enable better interpretation, the fit model tool of the JMP software was utilized to analyze the data; and specifically using the ANOVA, parameter estimates and prediction profiler. These had provided the basis for the evaluation and comparison of the performances of the different protocols for the cited scenario.

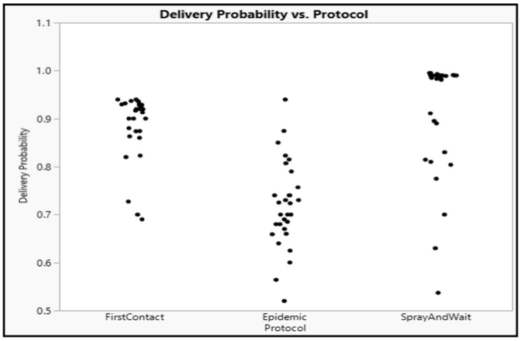
5 Results and Discussion

The effects of varying the factors: number of nodes, bit rate and ferry speed on delivery probability, latency, and overhead ratio were observed in the simulation and analyzed using the JMP software. The experiment consists of 30 runs for each protocol for a total of 90 runs. All the analyses were done using a level of significance of 0.05.

5.1 Factor Effects

The data obtained from ONE simulation were inputted to JMP for analysis, the results of which are shown in the succeeding sections: the built-in graph builder provided the visual comparison on the protocol performance in terms of the given metrics and table of parameter estimates for the mathematical models of the responses for each of the protocols.

Delivery Probability. The fit model derived from the ANOVA revealed that the factor that significantly has effect on delivery probability is the number of nodes. This implies that as the number of nodes is increased, the reliability of message delivery is also improved due to the custody transfer mechanisms inherent to the nodes. However, increasing the number of nodes in the network would mean increased network cost. The results also revealed that delivery probability is also significantly affected by ferry speed and the interaction effects of number of nodes and data rate, and of number of nodes and type of protocol. For this metric, SprayAndWait performed well obtaining an almost 100% message delivery depicted in Fig. 5a and b.



(a)

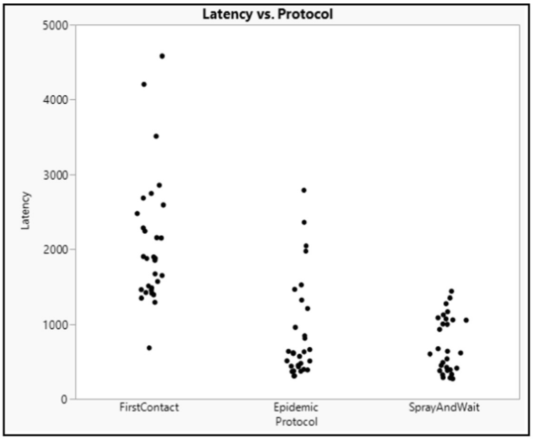
Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	0.8392211	0.007268	115.47	<.0001*
No. of nodes(12,40)	0.0887942	0.012265	7.24	<.0001*
Data rate(40,1375)	-0.009624	0.012056	-0.80	0.4271
Ferry speed(0.5,3.5)	0.0337241	0.012072	2.79	0.0065*
Protocol[FirstContact]	0.0446572	0.010358	4.31	<.0001*
Protocol[Epidemic]	-0.119871	0.010253	-11.69	<.0001*
Protocol[SprayAndWait]	0.0752141	0.010286	7.31	<.0001*
No. of nodes*Data rate	-0.043421	0.020779	-2.09	0.0399*
No. of nodes*Protocol[FirstContact]	-0.024244	0.018049	-1.34	0.1831
No. of nodes*Protocol[Epidemic]	-0.035996	0.017222	-2.09	0.0398*
No. of nodes*Protocol[SprayAndWait]	0.0602394	0.016996	3.54	0.0007*
Data rate*Protocol[FirstContact]	0.0218571	0.017591	1.24	0.2177
Data rate*Protocol[Epidemic]	-0.071815	0.017184	-4.18	<.0001*
Data rate*Protocol[SprayAndWait]	0.0499579	0.016957	2.95	0.0042*

First Contact Protocol: 0.8392 + 0.0447[FirstContact] + 0.089[No.of nodes] + 0.034[Ferry speed] – 0.0434[No. of nodes*Data rate]
Epidemic Protocol: 0.8392 – 0.1199[Epidemic] + 0.089[No.of nodes] + 0.034[Ferry speed] – 0.0434[No. of nodes*Data rate] – 0.036[No. of nodes*Epidemic] – 0.07[Data rate*Epidemic]
Spray and Wait Protocol: 0.8392 + 0.075[SprayAndWait] + 0.089[No.of nodes] + 0.034[Ferry speed] – 0.0434[No. of nodes*Data rate] + 0.06[No. of nodes*SprayAndWait] +0.05[Data rate*SprayAndWait]

(b)

Fig. 5. (a) Delivery probability vs. protocol (b) Parameter estimates using JMP

Latency. In terms of latency or delivery delay, the distribution plot shows a somewhat interesting pattern as shown in Fig. 6a. The values are dispersed in First Contact, less dispersed in Epidemic and least dispersed in SprayAndWait. The delay is almost reduced in half when SprayAndWait is used. This implies that the cooperation among the nodes in carrying the messages from other nodes speed up the delivery. Also with increasing data rate and ferry speed, the latency is reduced as revealed by the fit model in Fig. 6b.



(a)

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	1229.5359	48.72685	25.23	<.0001*
No. of nodes(12,40)	-709.3581	82.22511	-8.63	<.0001*
Data rate(40,1375)	-218.5721	80.82377	-2.70	0.0084*
Ferry speed(0.5,3.5)	-365.4387	80.93519	-4.52	<.0001*
Protocol[FirstContact]	882.41065	69.44147	12.71	<.0001*
Protocol[Epidemic]	-357.474	68.73961	-5.20	<.0001*
Protocol[SprayAndWait]	-524.9366	68.96117	-7.61	<.0001*
No. of nodes*Data rate	346.97069	139.3062	2.49	0.0148*
No. of nodes*Protocol[FirstContact]	-215.3028	121.0051	-1.78	0.0790
No. of nodes*Protocol[Epidemic]	-68.43108	115.4566	-0.59	0.5551
No. of nodes*Protocol[SprayAndWait]	283.7339	113.9424	2.49	0.0149*
Data rate*Protocol[FirstContact]	80.040637	117.9319	0.68	0.4993
Data rate*Protocol[Epidemic]	-35.54807	115.2051	-0.31	0.7585
Data rate*Protocol[SprayAndWait]	-44.49256	113.6841	-0.39	0.6966

First Contact Protocol: 1229.5 + 882.4[FirstContact] – 709.36[No.of nodes] – 218.6[Data Rate] - 365.4[Ferry speed] + 346.97[No. of nodes*Data rate]
Epidemic Protocol: 1229.5 – 357.5[Epidemic] – 709.36[No.of nodes] – 218.6[Data Rate] – 365.4[Ferry speed] + 346.97[No. of nodes*Data rate]
Spray and Wait Protocol: 1229.5 – 524.9[SprayAndWait] – 709.36[No.of nodes] – 218.6[Data Rate] – 365.4[Ferry speed] + 346.97[No. of nodes*Data rate] + 283.7[No.of nodes*SprayAndWait]

(b)

Fig. 6. (a) Latency (in ms) vs. protocol (b) Parameter estimates using JMP

From the analysis, latency is also significantly affected by ferry speed and the cross factor effects of number of nodes and type of protocol. Since the goal of the design is to minimize latency, therefore the protocol that performed well is the SprayAndWait because it provided the fastest delivery of the messages by sending out multiple copies of the message. This however, will result to high buffer times as can be seen in Fig. 7.

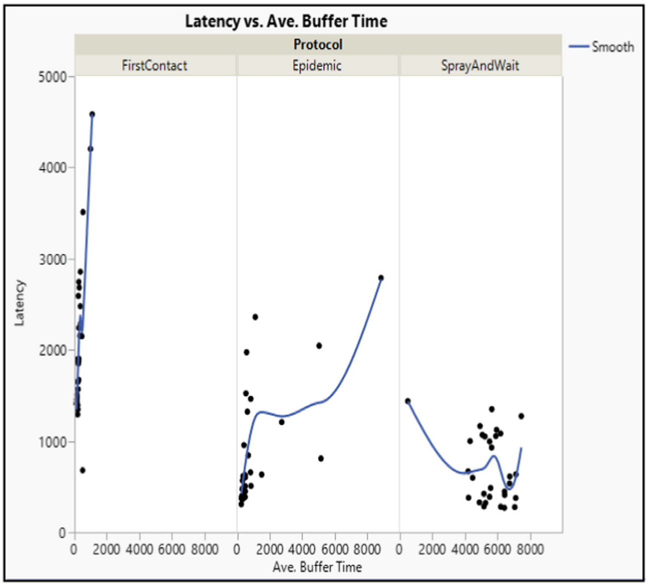
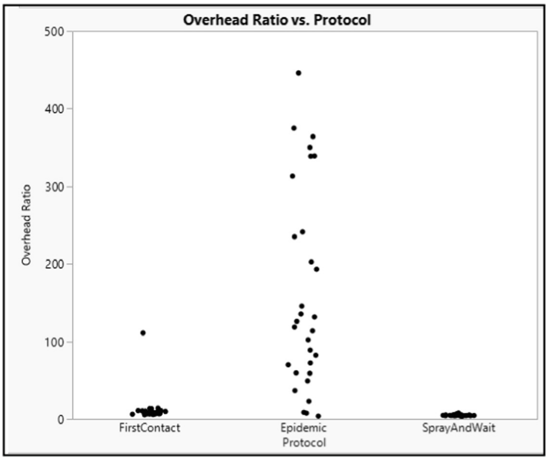


Fig. 7. Latency vs. average buffer time comparison using JMP

Overhead Ratio. As shown in Fig. 8a, the overhead ratio response for Epidemic protocol is dispersed from minimum to maximum while values for First Contact and SprayAndWait are closely intact at the minimum. This is expected since Epidemic has high overhead ratio because it makes more replications of messages than SprayAnd-Wait. From Fig. 8b, the ferry speed has no effect on the overhead ratio.

Average Buffer Time and Hop Count. Interestingly in the results, SprayAndWait registered a higher average buffer time compared to First Contact and Epidemic. And as expected from the results, lower latency results to higher buffer times. This is not the time spent while in buffer but this is the time spent during transit between intermediate nodes. The performance of the routing protocols is influenced by the number of message copies they create, thus First contact being single-copy runs faster than Epidemic and SprayAndWait. In terms of hop counts, SprayAndWait utilized lesser hops than the other two protocols and we can deduce that it also consumes lesser energy because of the lesser number of hops required to deliver the message.

Optimum Values. The prediction profiler tool of the JMP software computed the desirable values for each of the protocols. Maximum desirability is provided by the SprayAndWait with the following values: 34 nodes, 530 kbps data rate, and 2 m/s ferry speed. However, these parameter values that will give the optimum routing



(a)

Term	Scaled Estimate	Std Error	t Ratio	Prob>|t|
Intercept	59.793716	3.017178	19.82	<.0001*
No. of nodes(12,40)	50.273469	5.091399	9.87	<.0001*
Data rate(40,1375)	42.320375	5.004628	8.46	<.0001*
Ferry speed(0.5,3.5)	4.0459548	5.011526	0.81	0.4219
Protocol[FirstContact]	-49.39945	4.299833	-11.49	<.0001*
Protocol[Epidemic]	102.38525	4.256373	24.05	<.0001*
Protocol[SprayAndWait]	-52.9858	4.270092	-12.41	<.0001*
No. of nodes*Data rate	46.356119	8.625872	5.37	<.0001*
No. of nodes*Protocol[FirstContact]	-43.22715	7.492664	-5.77	<.0001*
No. of nodes*Protocol[Epidemic]	92.067331	7.149101	12.88	<.0001*
No. of nodes*Protocol[SprayAndWait]	-48.84018	7.055338	-6.92	<.0001*
Data rate*Protocol[FirstContact]	-48.8092	7.302369	-6.68	<.0001*
Data rate*Protocol[Epidemic]	92.293079	7.133527	12.94	<.0001*
Data rate*Protocol[SprayAndWait]	-43.48388	7.03935	-6.18	<.0001*

First Contact Protocol: 59.79 – 49.4[FirstContact] + 50.27[No.of nodes] + 42.3[Data Rate] + 46.36[No. of nodes*Data rate] – 43.23[No. of nodes*FirstContact] – 48.8[Data Rate*FirstContact]
Epidemic Protocol: 59.79 + 102.4[Epidemic] + 50.27[No.of nodes] + 42.3[Data Rate] + 46.36[No. of nodes*Data rate] + 92.06[No. of nodes*Epidemic] + 92.3[Data Rate*Epidemic]
Spray and Wait Protocol: 59.79 – 52.99[SprayAndWait] + 50.27[No.of nodes] + 42.3[Data Rate] + 46.36[No. of nodes*Data rate] - 48.8[No. of nodes*SprayAndWait] – 43.5[Data Rate*SprayAndWait]

(b)

Fig. 8. (a) Overhead ratio vs. protocol (b) Parameter estimates using JMP

performance are considered in this paper as both theoretical and ideal. It is to be expected that practical results from testbed deployments will differ considering the actual cost and range.

5.2 Summary

The results obtained from the experiments and analysis showed that the increase in number of nodes has a slight effect on the delivery probability in Epidemic routing while using more nodes resulted to significant increase on the delivery probability for SprayAndWait. Epidemic has high overhead ratio since it make the most replications of messages. This has consequences on storage capacity and energy consumption of the nodes. In terms of latency, SprayAndWait performed better than Epidemic but as the number of nodes was increased, both improved significantly while First Contact performed poorly. This implies that custody transfer and cooperation among the nodes speed up the message delivery. SprayAndWait utilized the least number of hops than epidemic and we can deduce that it also consumes lesser energy while First Contact utilized the most number of hops thus also utilizing the most energy. SprayAndWait registered higher average buffer time than the other two and it is expected because unlike Epidemic that performs flooding, SprayAndWait tends to "wait" until direct transmission to the destination is possible before transferring a message to a node. Buffer time in this context is not just the time spent while in buffer but added the time spent during transit between intermediate nodes. In over-all performance, SprayAndWait protocol is more favorable than Epidemic and First Contact. Maximum desirability is provided by the Spray and Wait protocol implying that this is the most suitable to the intended application. The results of the experiments validated the features of each of the protocols as described in the open literature.

6 Conclusion and Recommendation for Future Work

The evaluation of the protocol performance for the lake scenario considered the comparison of the effects of number of nodes, data rate, and ferry speed on delivery probability, latency, overhead ratio, average buffer time and hop counts. It was revealed by the results of the experiments that ferry speed has no significant effect on the protocol performance. However, this requires further investigation since it is a fact that mobility in a wireless radio system contributes to variations in the signal received. Map model of the lake scenario is utilized here to evaluate the three dominant DTN routing protocols. There are number of recently developed protocols that can be tested for this scenario. Energy expenditure which is an important design consideration needs to be tackled and incorporated to the proposed solution to the routing problem in a lake environment monitoring system under the premise of an intermittently connected delay tolerant network as described in this paper. Its full treatment can be part of future work.

References

1. Akyildiz, I.F., Su, W., Sankarasubramaniam, Y., Cayirci, E.: A survey on sensor networks. IEEE Commun. Mag. **40**, 102–114 (2002)
2. Karl, H., Willig, A.: Protocols and Architectures for Wireless Sensor Networks. Wiley, Hoboken (2005)
3. Gay-Fernandez, J.A., Sanchez, M.G., Cuinas, I., Alejos, A.V.: Propagation analysis and deployment of a wireless sensor network in a forest. Prog. Electromagnet. Res. **106**, 121–145 (2010)
4. Fall, K.: A delay-tolerant network architecture for challenged internets. In: Proceedings of SIGCOMM 2003, pp. 27–34. ACM, New York (2003)
5. Li, Y., Radim, B.: A survey of protocols for intermittently connected delay-tolerant wireless sensor networks. J. Netw. Comput. Appl. **41**, 411–442 (2014)

6. Wei, K., Liang, X., Xu, K.: A survey of social-aware routing protocols in delay tolerant networks: Applications, taxonomy and design-related issues. IEEE Commun. Surv. Tutor. **16**(1), 556–578 (2014)
7. Chenji, H., Hassanzadeh, A., Won, M., Li, Y., Zhang, W., Yang, X., Stoleru, R., Zhou, G.: A Wireless Sensor, AdHoc and Delay Tolerant Network System for Disaster Response (2011). https://engineering.tamu.edu/media/696805/2011-9-2.pdf
8. N4C: Networking for communications challenged communities: architecture, test beds and innovative alliances (2007)
9. Del Rosario, J.M.: Deployment of a wireless sensor network for aquaculture and lake resource management. In: IEEE First International Workshop on Wireless Communication and Networking Technologies for Rural Enrichment (2011)
10. Solpico, D.B.: Towards a web-based decision system for Philippine lakes with UAV imaging, water quality wireless network sensing and stakeholder participation. In: ISSNIP 2015 (2015)
11. The Agroecosystems of Buhi: Problems and Opportunities. http://pdf.usaid.gov/pdf_docs/Pnaau489.pdf
12. Alnuaimi, M., Shuaib, K., Alnuaimi, K., Abdel-Hafez, M.: Data gathering in delay tolerant wireless sensor networks using a ferry. Sensors **2015**(15), 25809–25830 (2015)
13. Cerf, V., Burleigh, S., Hooke, A., Torgerson, L., Durst, R., Scott, K., Fall, K., Weiss, H.: Delay-tolerant networking architecture. RFC 4838 (Informational), April 2007
14. Scott, K., Burleigh, S.: Bundle protocol specification. RFC 5050 (Experimental), November 2007
15. Cao, Y., Sun, Z.: Routing in delay/disruption tolerant networks: a taxonomy, survey and challenges. IEEE Commun. Surv. Tutor. **15**(2), 654–677 (2013)
16. Keränen, A., Ott, J., Kärkkäinen, T.: The ONE simulator for DTN protocol evaluation. In: Proceedings of the 2nd International Conference on Simulation Tools and Techniques (Simutools 2009). ICST (Institute for Computer Sciences, Social-Informatics and Telecom Engineering), Brussels, Belgium, Article no. 55 (2009)
17. Vahdat, A., Becker, D.: Epidemic routing for partially connected ad hoc networks. Technical report CS-200006, Duke University, April 2000
18. Spyropoulos, T., Psounis, K., Raghavendra, C.S.: Spray and wait: an efficient routing scheme for intermittently connected mobile networks. In: Proceedings of the 2005 ACM SIGCOMM Workshop on Delay-Tolerant Networking, WDTN05, pp. 252—259. ACM, New York (2005)
19. The One. https://www.netlab.tkk.fi/tutkimus/dtn/theone/
20. Space-Filling Design. http://www.jmp.com/support
21. Open Jump. http://www.openjump.org/