Simulation-Based Performance Comparison for Variants of Spray and Wait in Delay Tolerant Networks

Mohammad Abdul Azim[1], Beom-Su Kim[1], Kyong Hoon Kim[1], Ki-Il Kim[2,*]

[1]Department of Informatics, Gyeongsang National University, Jinju, Korea.

[2]Department of Computer Science and Engineering, Chungnam National University, Daejeon, Korea.

Received 16 October 2016; received in revised form 26 January 2017; accepted 31 January 2017

Abstract

Delay Tolerant Network (DTN) has been proposed to deliver data packets in an intermittently connected network by the store and carry technique. Among many existing routing protocols in DTN, spray and wait and its variants are based on replication by allowing the number of copies per message in the network but they still include some problems. To address energy issue and delivery ratio, we have presented the spray and fuzzy forwarding (S&FF) to employ the fuzzy inference systems (FIS). However, since our previous performance comparisons are simply evaluated over few cases, more extensive simulation scenarios need to be executed for accurate performance comparison. Based on this demand, in this paper, we compare S&FF with some variants of spray and wait in diverse aspects and provide analysis for their simulation results. Through the simulation results, we can observe that delivery ratio is acceptable while extending network lifetime in S&FF rather than comparable protocols under varying deadlines, the number of nodes and velocities.

Keywords: delay tolerant networks, spray and wait, spray and fuzzy forwarding, performance evaluation

1. Introduction

In intermittently connected networks, traditional networking approaches are likely to fail due to the unavailability of links at specific instances. In such a situation, DTN [1] can provide communication capability by introducing the store-and-carry technique. Furthermore, DTN is expected to play a great role in perspective space communication through Interplanetary Internet as addressed in [2] as well as ad hoc or infrastructure based communications for vehicular DTN in [3].

Among the existing routing protocols, Epidemic Routing (ER) [4] is an approach that floods the message throughout the network, obviously to achieves maximized routing performance when no constraints exist on network resources. Thus, in realistic settings where the resources (e.g., buffer space, bandwidth, and battery) are limited, its scope of applicability is not bounded. Specially, under highly loaded situation, it suffers from severe congestion and messages drop due to the huge number of redundant message copies that result in significant degrading its performance and scalability. To alleviate these shortcomings of ER, the controlled replication or spraying routing protocols [5-6] have been proposed. The key features of these algorithms are to exploit node characteristics (e.g., encounter history, mobility pattern, and network topology) by generating only a smaller number of message copies than Epidemic.

On the other hand, Spray and Wait (S&W)[7] is another type of such DTN protocol to handle data without any underlying knowledge about the network. S&W is an extremely appropriate technique at the early deployment phase of DTN when the network statistics are not available yet. After this period is over, S&W suffers from several drawbacks such as poor delivery probability. The main reason for poor performance is that S&W ignores significant obtainable information at all. To solve this

* Corresponding author. E-mail address: kikim@cnu.ac.kr

Tel.: +82-42-821-6856; Fax: +82-42-821-8996

problem, Spray and Focus (S&F)[8] overcomes aforementioned drawback of S&W by employing a utility-based routing metric. However, since S&F utilizes highly connected nodes over and over again inappropriately in forwarding phase, battery of these nodes is expected to be quickly depleted in the subgroup of nodes. This results in early disintegration of the network and short network lifetime. In addition, this phenomenon is too common to any DTN communication approach which is aggressively intended for high delivery probability without considering resource consumption.

As mentioned above, the impact of network lifetime in the most of DTN context is not generally concerned. This implies that packet delivery ratio becomes lower and lower as operational time goes. To address the aforementioned issues, we have developed the Spray and Fuzzy based Forwarding (S&FF) protocol [9] that is intended to gracefully maintain delivery probability in the energy constrained DTN. S&FF utilizes the well-known Fuzzy Inference System (FIS) to handle the conflicting phenomenon when there are no clear correlations among routing metrics. However, since little performance analysis is previously carried out, it is demanded to perform comparison through more extensive scenarios. These extensions aim to cover the analysis of the impact on the performance according to different network environments: (i) a different number of deployed nodes (ii) different node velocities and (iii) varying deadlines. As addressed in [10], since study based on comparative performance plays a great role in protocol design by highlighting the weakness and disadvantage, we choose the most well referred performance metrics from other literatures and provide appropriate analysis for them. The measured performance metrics involve the delivery probability as well as the energy consumption in this paper. Furthermore, as motivated by [11], we choose a human-like mobility model named Spatio-TEmporal Parametric Stepping (STEPS)[12] that captures the movements more realistically to evaluate the comparable protocols instead of inadequate of traditional mobility models such as random waypoint in DTNs.

The rest of this paper is organized as follows. Followed by the research background, three major comparable protocols are briefly explained in section 2 for a better understanding of their operations. We present the simulation results and analysis in section 3. Finally, conclusion and further work are given in section 4.

2. Related Work

Fuzzy-spray and wait [13], the adaptive priority routing protocol (APRP) [14] and adaptive fuzzy spray and wait (AFSnW) [15] are known as variants of S&W where the adequate buffer prioritization and dropping policies are applied to the fuzzy systems. But, none of these fuzzy based approaches provide a forwarding mechanism. On the other hand, the S&FF is completely different an approach in that it is focusing on forwarding.

Spray and dynamic approach [16] improves and modifies the original spray and wait by incorporating the functionality of both MaxProp [17] and being transferred by delegation model [18]. Since this approach assumes the no change on the capability of a node, an unrealistic assumption suffers when network conditions are varied. A utility metric utilizing Bayesian signaling game is proposed in [19]. Similarly, a delivery likelihood based spraying is presented in [20]. A DTN specific communication technique [21] is proposed for the routing decision of the network by employing the well-known Dijkstra networks. But, since it is based on an unrealistic assumption for centralized operation, it is not scalable and suitable for large dynamic networks.

Bulut *et al.* introduce a mechanism of spraying the copies of the packets in different time intervals (two intervals/three intervals) in [22]. The protocol initially sprays the message with less number of copies. However, if the message fails to reach the destination after a predefined period, another large number of packets are sprayed. E. Bulut et al., have extended this protocol by generalizing intervals of spraying in [23]. However, these protocols also do not provide any forwarding mechanism. To avoid the aforementioned issues, to this end, we introduce S&FF to avoid resource exhaustions by utilizing the FIS feeding with routing table through practical metrics while maintaining a reasonable delivery ratio.

3. Comparable Protocols

3.1. *Spray and Wait (S&W)*

The traditional DTN communication approach of S&W protocol has attracted intense attention from the research community due to its simplicity as well as the competency of handling communications where there is no available knowledge in regards to routing metric. To realize communications in DTN, S&W sprays a predefined number of data copies into its neighborhood. Upon receiving a copy of the packet, a node operates on the store-and-carry scheme in a way that the node holds the data until it meets the destination node. After discovering the destination node in the neighborhood, the node finally delivers the corresponding packet to the destination. The aforementioned simplicity and corresponding strengths are associated with a number of weaknesses and disadvantages such as high buffer occupancy as well as a poor Delivery Ratio (DR). It is likely that building a routing table over the time through specific network knowledge contributes to better performance in terms of both buffer occupancy and DR.

Mode detailed, note that the DR is defined as DR = N_R / N_S, where N_S and N_R stand for the total number of packets sent by the sources and the total number of packets successfully received at the destinations, respectively. Consequently, a number of spray based forwarding approaches have been developed by utilizing gathered information. In general, these spray based forwarding approaches provide better delivery probability in the DTN.

3.2. *Spray and Focus (S&F)*

S&F is one of spray family of protocols that exploit the forwarding opportunity and provide high DR. S&F is largely dependent on a routing table based on a utility metric. This metric is then utilized to forward the packets through a number of intermediate nodes. In a counter based approach of the utility, S&F initializes the routing cost of all nodes towards all the destinations with infinity. Each node updates the cost in each interval. When a predefined interval is over, each node increments cost in its routing table by adding 1. In case that a node meets another node, cost of corresponding entry resets to zero. Upon finding an entry having particular cost less than previous cost entry, a node forwards the updated information to its neighbors and keeps the routing table fresh. In case that there exists any node in the neighborhood that holds a cost to the destination less than the cost of the current node, the packet is passed to the corresponding neighbor.

By using this procedure, the S&F in turn passively forms a backbone with highly connected nodes and passes packets towards the destination through minimum delayed fashion. S&F consecutively improves message delivery probability by utilizing the same high-performance specific nodes to forward. Therefore, in an energy resource constrained environment, this strength exhibits an undesirable characteristic of network partitioning due to quick battery drain caused by a large number of transmissions. Consequently, it results the early deaths of the subset of the nodes involved in forwarding. Such phenomena are quite likely to be observed in any approach similar to S&F that is aggressively designed for high delivery probability.

3.3. *Spray and Fuzzy based Forwarding (S&FF)*

S&FF design goal is to gracefully maintain the delivery probability in a prolonged lifetime. S&FF provides forwarding decision in DTN by utilizing the FIS which is similar to multi-criteria decision system that optimizes (i) intermeeting time (τ), (ii) remaining energy (E) and (iii) number of successful forwarding (N) (metrics collected in the routing table). To achieve this, we define the routing table and algorithm to decide forwarding. In other words, the next node is selected by the inputs (i.e., the routing table) of the FIS. Therefore, this algorithm consists of three following blocks, that is, identifying potential relays, membership functions and forwarding decision.

3.3.1. *Potential Relays*

Over the period, a node carrying a packet encounters other nodes. The node evaluates the meeting nodes and finds the possible relay nodes among them. These relay nodes are likely to have shorter intermeeting times than the source. A potential relay, therefore, is the one having shorter intermeeting time than the source.

3.3.2. *Membership* Functions

The fundamental building blocks of the FIS are the membership functions that define the input-output relationships of each defined metric. Subsequently, three distinct membership functions are therefore defined corresponding to each defined metric. These three membership functions of the intermeeting time, remaining energy and number of successful forwarding are defined by Eq. (1) - Eq. (3), respectively.

$$\theta_i^\tau = e^{\tau_i} \tag{1}$$

$$\theta_i^E = (1 - E_i) \tag{2}$$

$$\theta_i^N = \frac{1}{N_i} \tag{3}$$

Here, θ_i^τ, θ_i^E and θ_i^N are the outputs of the membership functions made up of intermeeting time, remaining energy and number of successful forwarding respectively for the i^{th} node. And τ_i, E_i and N_i are the inputs to the corresponding membership functions. τ_i stands for the intermeeting time between the candidate neighbor i and the destination. E_i and N_i stand for the dissipated energy of the candidate neighbor i and the number of successfully forwarded packets by the candidate neighbor, respectively.

In S&FF, all above values in the routing metrics are collected locally. In details, the values are transmitted in single hop broadcast. The HELLO message in S&FF contains the information of all the metrics of the current node. Upon receiving the message, neighbor nodes update the values in the table and run the decision algorithm. The construction of S&FF carefully avoids the metrics that require multi-hop propagation.

- Intermeeting time: Intermeeting time represents the average time between two successive meetings of the corresponding nodes. This statistic essentially is integrated into the routing decision as this membership function. The membership function is defined such that the cost i.e., the output of the membership is exponential to the input. This characteristic conform our membership definition that the frequency is the reciprocal to the intermeeting time.
- Remaining energy: To be effective on energy dissipation, this algorithm intends to dissipate energy evenly throughout low energy devices. Thus, the proposed algorithm needs to track the remaining energy of the whole nodes. As data forwarding is enormous energy dissipative, the energy resourceful nodes contribute to forward more packets than low energy ones in the neighborhood. Consequently, E_i is the dissipated energy of the node i where its value of the full battery is denoted as 1.
- Number of successful forwarded packets: Intermeeting time has an elegant characteristic of forwarding decision. Nevertheless, poor performance is expected to be measured in situations where some specific nodes with low intermeeting time are deployed. This is because its attribute causes following issues like high buffer occupancy, short connection time, etc. Thus, this parameter provides an outcome based measurement.

3.3.3. *Forwarding Decision*

Both inputs and outputs need to be normalized. A simple normalization approach suffices for this purpose and may be given by $x = \frac{x}{max\,(x)}$ and $y = \frac{y}{max(y)}$ in relations to the inputs and outputs where x and y stand for the input and output sets, respectively.

Using the outputs of the membership functions as the heights of the trapezoids, the areas of the trapezoids are derived by Eq. (4). Subsequently, the weighted averages belonging to the corresponding nodes are derived by employing Eq. (5).

$$\delta_i^\gamma = \frac{1-(1-\theta_i^\gamma)^2}{2} \tag{4}$$

$$\phi_i = \frac{\sum_{\gamma=1}^{\lambda} \delta_i^\gamma \, \omega_\gamma}{\sum_{\gamma=1}^{\lambda} \omega_\gamma} \tag{5}$$

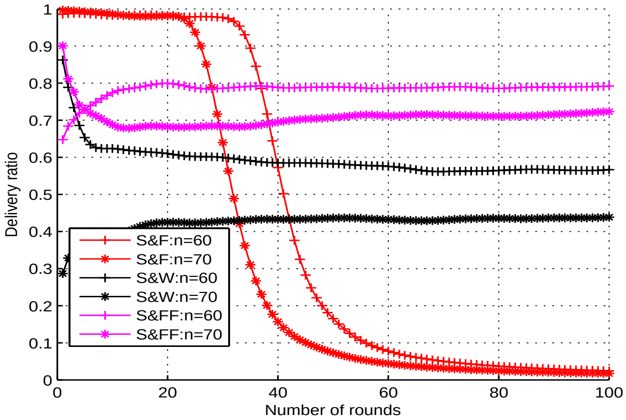
Here, θ_i^γ and δ_i^γ stand for the output of the membership function γ of node i and the area of the corresponding trapezoid, respectively. ϕ_i stands for the desired final weighted average corresponding to the particular node i. And ω_γ represents for the weight of that particular membership function, γ. The node having the minimum ϕ holds the best characteristics meant for participating in the forwarding role.

4. Performance Comparison through Simulation

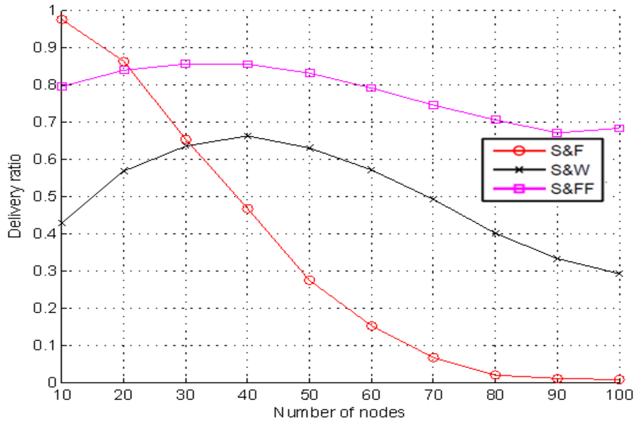
In this section, extensive simulations are carried out in Matlab to comprehend the behavior of the comparable protocols i.e., S&W, S&F and S&FF. Spatio-TEmporal Parametric Stepping (STEPS) is taken as the mobility model due to its close relationship with the human mobility model. The aspects of the comparisons include (i) different number of nodes in the networks (ii) changing velocities of the nodes and (iii) different deadlines specific to the application requirements. STEPS models the velocity as $\upsilon = [\upsilon_{min} \ \upsilon_{max}] \, \xi$. Here, υ_{min} and υ_{max} stand for the maximum and minimum values of the velocities and chosen as 0.8333 and 2.7778, respectively for whole simulations. The design parameter ξ is a scalar multiplier that is varied from 1 to 5 to model the increasing velocities of the nodes in the DTN. For all scenarios, the size of the field is fixed and set to 200x200m^2. Parameter n denotes the number of nodes. A number of 500 packets are generated in each node in a round where each packet is destined to a randomly selected destination. The deadline and transmit range are denoted as λ and μ. The nodes are assumed as constrained powered and capable of transmitting a total number of 10^5 packets. The transmit power of a node and the packet transmit time is chosen as 3.78mW and 100ms. The time between successive recharges of the nodes consists of 100 rounds.

4.1. *Number of Deployed Nodes*

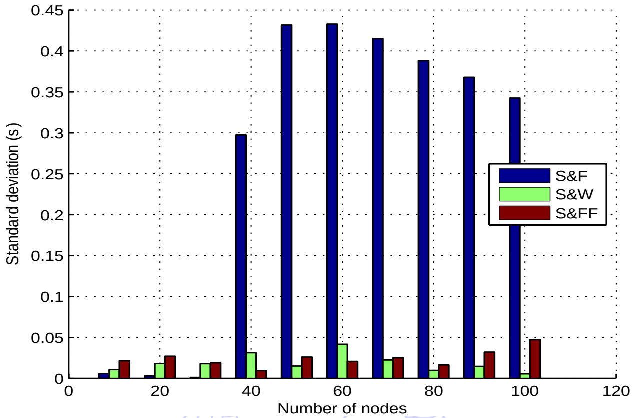
The performance of the protocols with different number of deployed nodes is evaluated and presented in this subsection. Fig. 1 deals with the DR of the protocols, where the parameters k, μ, λ and ξ are set to 100, 20, 255 and 5, respectively. Fig. 1 (a) provides the DR performance of the protocols in each round. The S&F outperforms the S&W and S&FF in the initial rounds. However, unfortunately, the performance of S&F does not sustain after a number of rounds. This indicates that the DR performance declines abruptly and soon after the DR performance of S&F becomes unacceptably low. With an increased number of deployed nodes, the disintegration starts in earlier rounds. The sharp declining of DR in rounds results in poor average DR in S&F with exceptions to the network composing of a small number of nodes. Fig. 1(b) provides the average DR of the protocols for different number of deployed nodes. The x-axis provides the information of the total number of nodes (n) deployed in a particular scenario. Here, n is set to 10 to 100 with an increment of 10. The results reveal that S&F performs the best when n<20. S&FF performs the best for the rest of the deployment i.e., n>20. S&W never performs the best for this particular evaluations. The performance of S&F in case of n>30 is even worse than S&W. Fig. 1(c) provides the standard deviations (σ) of the protocols in different node deployments and reveals that σ of S&F is extremely high in case of n>=40. The higher σ is unwanted due to the inconsistencies in DR performances among the early and later rounds. A high σ provides the indication to the unsustainable nature of the S&F protocol.



(a) Impact on DR in rounds

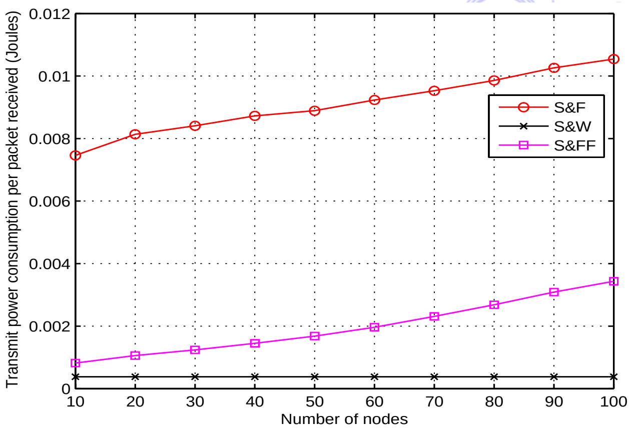


(b) Average delivery ratio

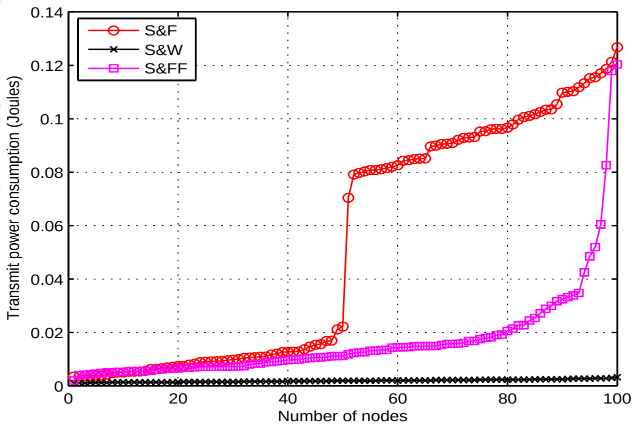


(c) Standard deviation of the delivery ratio

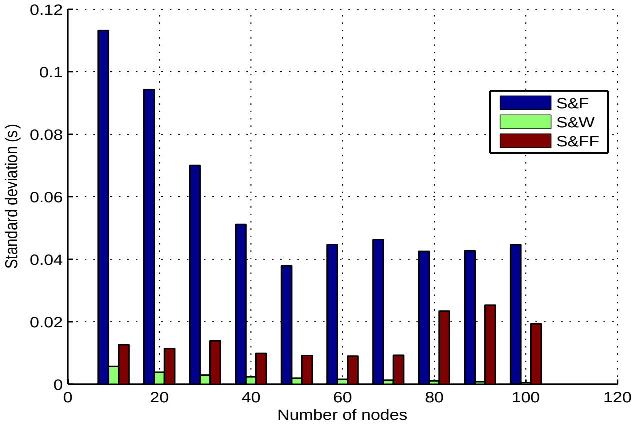
Fig. 1 Impact of different number of node deployments over delivery ratio (k=100, σ =20, λ=255 and ξ=5)



(a) Transmit power consumption per packet received



(b) Sorted energy consumption of the individual nodes



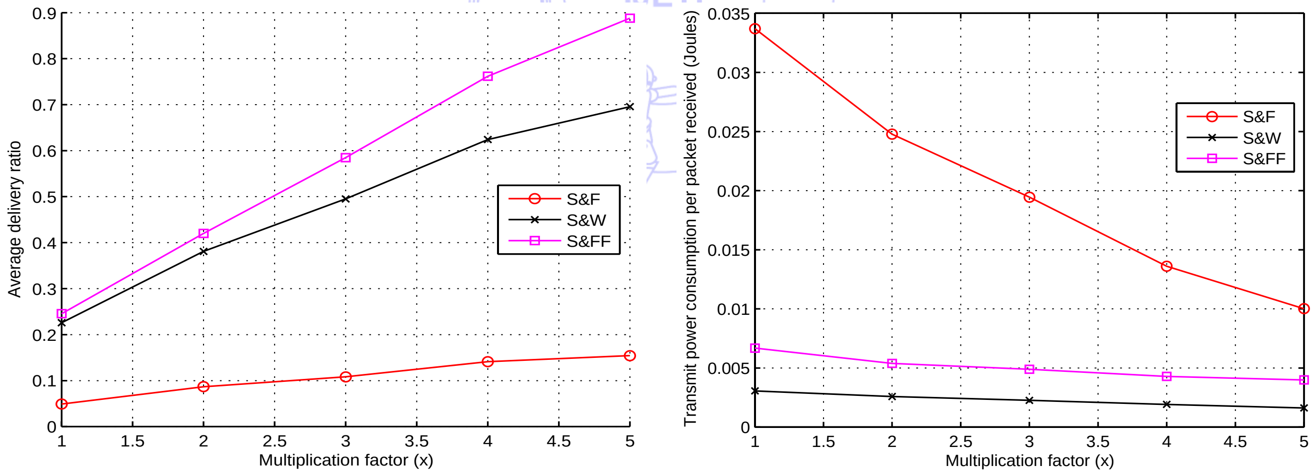
(c) Standard deviation of the node energy consumption

Fig. 2 Impact of different number of node deployments on energy consumptions (k=100, σ =20, λ=255 and ξ=5)

Fig. 2 presents the energy consumptions of the protocols in different perspectives. The different parameters are set to k=100, σ=20, λ=255 and ξ =5. Fig. 2 (a) depicts the transmission energy consumption per successfully received packet at the receiver in different deployments where n is varied from 10 to 100 with 10 increments. S&F shows the worst; on the contrary, S&W shows the best energy consumption characteristics. Note that the energy consumption rate increases in increasing of n. To figure out how the energy consumption is distributed in individual node, we capture the energy dissipation on each node after 10^3 packets received at the destinations (n=100). Fig. 2 (b) reveals the insight into the reason behind the sharp declining of the DR in S&F. This is due to the fact that a number of nodes (about 50%) are utilizing a large amount of energy resource. This high energy consumption on these specific nodes leads to early death of the backbone nodes. Fig. 2 (c) provides the variance σ in energy consumption rate in different number of deployed nodes. This figure reveals that the σ is extremely high in S&F as compared to the S&W and S&FF. In case of a small n, the σ of S&F becomes higher than other two protocols.

4.2. Velocities

Fig. 3 shows the response of the protocols in different velocities, where k, n, λ and μ are set to 100, 40, 255 and 20, respectively. The increasing velocity is modeled by increasing of ξ where ξ is set to 1 to 5 with increments of 1. Fig. 3 (a) depicts the average DR of the protocols in different velocities. Increasing the velocities results in decreasing the intermeeting time and increasing of connectivity in the network, consequently. This in turn brings increasing the average DR in all the protocols. S&FF provides the best result among all comparable protocols for all the settings of ξ. In contrast, S&F provides the worst performance because of the averaging effect of both extremely good earlier round responses and the extremely poor later round responses of the protocol. The rate of increase in the average DR become slower with the increase of ξ. Fig. 3(b) provides the transmission power consumptions per successfully received packet in varying ξ. For all the cases, the rate of such power consumption decreases as for increasing ξ. This is because the DR is improved according to increasing ξ. Even though the rate of decreasing the power consumption is the best in S&F among all, it is never able to catch the others.



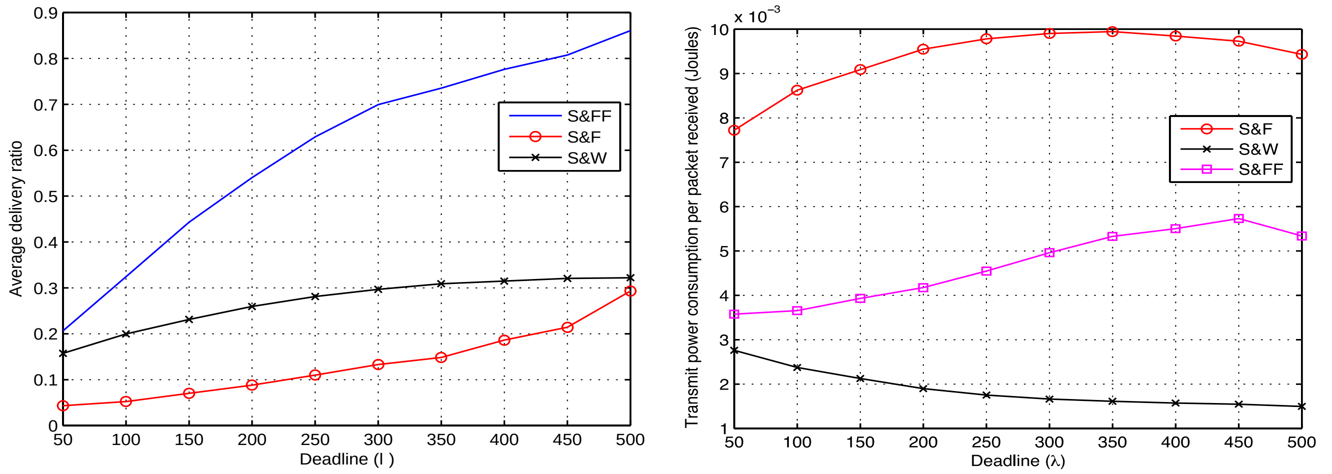
(a) Impact on average DR

(b) Transmit power consumptions in each successfully received packet

Fig. 3 Impact of different velocities on the protocols (k=100, σ =40, λ=255 and ω=20)

4.3. Deadlines

Fig. 4 shows the performance comparisons of the protocols in varying deadlines (λ) with the parameter settings of k=100, n=100, ζ=5 and μ=20. The λ is varied from 50 to 500 with an increment of 50. Fig. 4(a) shows the average DR performance of the protocols with different λ where S&FF considerably leaves behind S&W and S&F. Conversely, performance of S&F is the worst among all. After a significant increase in the deadline, S&F merely catches S&W. Fig. 4(b) depicts the transmission energy consumption rate of the protocols in different settings of λ. S&W shows the best value where S&F performs the worst. Increasing λ increases energy consumption rates for both S&F and S&FF with some exceptions in high λ. Interestingly, increasing λ results in decreasing of consumption rate. This is due to the fact that increasing λ in both S&F and S&FF causes potentially number of transmissions due to forwarding. On the other hand, due to the non-forwarding policy of S&W, the number of transmission of S&W remains the same. The decreasing consumption rate comes from increasing in delivery probability of the packets for increasing λ.



(a) Impact on average DR

(b) Transmit power consumptions in each successfully received packet

Fig. 4 Impact of different deadlines on the protocols (k=100, σ =100, ζ = 5 and ω=20)

5. Conclusion

In this paper, we presented the simulation based performance evaluation for original S&W and its variants including S&F and our S&FF. In summary, S&FF performance results imply that it is most suitable communication technique in the resource constrained DTN. S&W provides the best energy performance with the tradeoff having low DR compared to S&FF. S&F fails to handle energy resource constrained networking approach of DTN appropriately so it becomes the worst among the comparing protocols. Contrarily S&F would be the most suitable protocol among these protocols in an unlimited resource DTN (often impractical).

Related to this work, other performance evaluations under different mobility models will be conducted. As another direction, we will evaluate other family protocols together in several aspects. These analysis results will lead to develop new routing protocol to improve delivery ratio while extending network lifetime.

Acknowledgments

This work was supported by Basic Science Research Program (2015R1D1A1A01056979) through the National Research Foundation of Korea (NRF) funded by the Ministry of Education.

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