Framework for Utility Driven Congestion Control in Delay Tolerant Opportunistic Networks

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Abstract — **Detecting and dealing with congestion in delay tolerant opportunistic networks is an important and challenging problem. In this paper we describe CAFREP, a unified congestion control framework for routing in such networks that adapts both data sending rates and data forwarding policies through a novel reactive fully distributed approach. CAFREP enables congestion control by detecting and reacting to congested nodes and congested parts of the network by using implicit hybrid contact and resources congestion heuristic. CAFREP exploits localized relative utility based approach to offload the traffic from more to less congested parts of the network, and replicate at adaptively lower rate in parts of the network with higher congestion. We extensively evaluate CAFREP against a number of state of the art adaptive and non-adaptive DTN routing protocols across a number of different metrics over three real trace driven experiments with different mobility and connectivity patterns such as Infocom 2006, Rollernet and Dieselnet CRAWDAD data sets. We show that CAFREP performs well in three different connectivity datasets and continuously outperforms four other protocols in terms of maintaining higher node availability and success ratio while keeping lower delays, lower packet loss rates and lower number of forwarded packets for increasing congestion levels.**

Keywords - DTN, Routing, Congestion

I. INTRODUCTION

Delay tolerant opportunistic networks do not perform well under finite storage and/or transmission constraints. Existing contact analysis techniques [1,5,13,14] that are typically used to increase the "probability to deliver" to a destination node and to minimise delays lead to load being unfairly distributed towards better connected nodes and can produce single node and network wide congestion [2,10,11,12]. For example, more popular people or hotspots in social networks [9] and road side units in the vehicular networks can get overloaded or unusable, and new techniques are needed to offload such hotspots and distribute the traffic away from them. If not handled within the routing protocol, congestion in opportunistic and delay tolerant networks may take the form of persistent storage exhaustion [2]. Traditional congestion control protocols that are integral to the stability of the Internet are unusable because they assume contemporaneous end-to-end connectivity and use closed loop control as they rely on acknowledgments. Open-loop congestion control protocols are much better suited to opportunistic networks where global view of the network is unavailable and volatile, but they have not yet been extensively studied and integrated in current opportunistic protocols.

Newly emerging work on adaptive routing and congestion control in DTNs can be divided in two groups: adaptive forwarding [10,11,12], and adaptive replication techniques [6,7,8,21] Adaptive forwarding (assuming single copy) protocols [10-12] propose an open loop, localized, utility driven forwarding protocol that diverts the load from its conventional node centrality-driven path when the congestion signals are detected and spreads it across multiple paths in order to route away from the congested area. This approach of forwarding packets along multiple paths is suitable to social opportunistic networks as they have been shown to have huge diversity of forwarding paths in human contact networks [7] as well as to any other types of complex networks where not all the nodes are equally likely to encounter each other and thus deliver the messages to the designation (such as vehicular networks). The main drawback of these adaptive forwarding techniques approaches is that they do not decrease the total level of traffic in the network but merely redirect it. This means that they suffer at times of high congestion when finding alternative non-congested parts of the network is not possible. Adaptive replication techniques [6,7,8,21] can detect congestion and decrease the traffic in response but they cannot adaptively offload the traffic from more congested to less congested parts of the network. This means that they cannot efficiently deal with persistent congestion at some parts of the network while the other parts are less congested.

After a review of related work on adaptive routing and congestion control in DTNs in Section II, Section III proposes to unify adaptive forwarding and adaptive replication into a common congestion control framework for DTNs (CAFREP) that manages to both decrease the load on the network and offload the traffic to the parts of the network that are less congested. We achieve this by using a local based implicit heuristic based on contact and resource statistics that extends our previous work on adaptive forwarding [10-12]. More specifically, we propose to dynamically combine three types of heuristics: node centrality and contact analysis driven heuristics that exploits contact relationships to allow optimal directionality and delivery probability of a node; node resource driven and ego network driven heuristics to detect and react to the nodes or parts of the network that have low buffer availability, high delays or high congesting rate. As a result, our new framework adaptively changes forwarding and replication behaviour by using combined heuristic relative utility that best manages tradeoffs across multiple contact and resource attributes of nodes in real network scenarios with different mobility, and connectivity patterns. As nodes' encounter patterns can greatly differ for social, vehicular and mixed networks, in Section IV we evaluate our CAFREP across three different real traces from three different CRAWDAD datasets in order to gain better understanding of our protocol performance. We use a realistic publish subscribe podcasting application for data transfer and we generate different congestion levels. We present an extensive evaluation of CAFREP against both adaptive and non adaptive DTN routing protocols across a number of metrics such as packet loss, number of forwarded packets, success rate, delays and availability. Our results show two main contributions: 1) CAFREP achieves high success ratio and node availability while maintaining low delays, packet loss and number of forwarded packers in all three real connectivity traces: RollerNet [18], Infocom 2006 [15] and DieselNet [19] 2) CAFREP outperforms EBR [8], RR[21], Prophet [20], Spray and Focus [13] and CAFÉ [10,11,12] across all the criteria in all three CRAWDAD scenarios, Section V gives conclusions.

II. RELATED WORK

This section discusses a number of newly proposed methods that identify key properties in the DTNs that allow for more intelligent and adaptive forwarding and message replication techniques than in the traditional DTNs.

[7,8,21] observe that overloading of a single node in a DTN does not indicate that there is network-wide congestion and that the number of copies allowed for the messages needs to be adaptive. [8] propose EBR, a quota-based replication protocol, where each node tracks its rates of encounters in order to intelligently decide how many replicas of a message a node should transfer during a contact opportunity. The appropriate fraction of message replicas the nodes should exchange when they meet is determined by the relative ratio of their respective rates of encounters. [7,21] develop a dynamic, local approach to detect and respond to congestion by adjusting the copy limit for new messages. In their work DTN nodes use implicit indicators to detect congestion based on gathered network metrics from their contacts with other nodes. The protocol proposes the nodes to create their own congestion view (CV) as the ratio of drops and duplicate deliveries and compare it to the congestion threshold. Depending on the comparison the copy limit for new messages is lowered or raised following a back-off algorithm. This work assumes a uniform network with random waypoint mobility. In reality the networks are likely to be non-uniform and the level of congestion may vary between different regions of the network. This work has not proposed how the network adjustments would compensate for differing local conditions.

[6] propose DA-SW (Density-Aware Spray-and-Wait), that is a measurement-oriented variant of the spray-and-wait [S&W] algorithm that dynamically determines the number of a messages disseminated in the network in order to achieve constant delay. DA-SW relies on the current average node degree in the roller tour. Whenever a node has a bundle to transmit, it computes its current connectivity degree and refers to the abacus to determine the exact number of copies that is expected to lead to some expected delay. The authors did not address the impact of their static measurement window (30sec) on the performance of their system. This work does not consider dealing with resource constraints such as node buffers, bandwidth and energy consumption.

[6,7,8,21] do not adaptively set the total number of copies per message even though they agree this would be beneficial. [8] presents analysis using different values for L and decides to use 11 initial copies per message. [21] sets the limit of the maximum number of replicated message on each encounter. [6] use abacus in order to determine the suitable value for L but when calculating the abacus they assume that they have the knowledge of the total number of nodes participating.

In [10,12] we propose and examine several combined social and resources heuristics in order to detect congested parts of the network and move the traffic away towards less congested parts. These heuristics include social, delay and buffer metric of nodes and their ego networks. The total combined utility function we propose is at the core of our adaptive forwarding protocol that is dynamic and flexible as it operates as a pure social (contact driven) protocol at times of low congestion but is highly resource driven at times of high congestion. We show that our single copy adaptive forwarding protocol achieves better performance in comparison to multi-copy protocols such as spray and wait (SW), spray and focus (SF)[13], Prophet [20] and epidemic protocols in terms of decreased delays, higher availability of nodes and higher success ratios.

In [11] we build an interest-driven P2P content dissemination overlay on the top of our congestion aware forwarding protocol. Both caching and forwarding policies are decided based on the interest, availability, social closeness and numbers of interested nodes. Our results show that our adaptive overlay manages to maintain high success ratio of answered queries, high availability of intermediary nodes and short download times for a P2P file casting application running in the face of increasing number of file publishers and topic popularity.

III. CONGESTION AWARE FORWARDING AND REPLICATION (CAFREP)

This section describes unified adaptive forwarding and adaptive replication management approach into a common congestion control framework for DTNs routing, CAFREP (Congestion Aware Forwarding and Replication). CAFREP manages to both decrease the load on the network and offload the traffic to the parts of the network that are less congested at times of increasing congestion. We achieve this by using a local open loop implicit heuristic based on the contact and resource analysis metrics. The architectural overview of CAFREP node is given in Figure 1. For forwarding and replication heuristics, we dynamically combine three types of heuristics: contact driven heuristics that exploits contact relationships among nodes to allow optimal directionality and delivery probability of a node; node resource driven heuristics that aims to detect and adopt to the nodes that have low buffer availability (node retentiveness, as we defined it in [10]), high delays (node receptiveness, as we defined it in [10]) or high congesting rate[12]; and ego network driven heuristics that aims to detect and adapt to the parts of the networks that have low buffer availability (ego network retentiveness, as we introduced it in [12]) and increased delay (ego network receptiveness, as we introduced it in [12]). Selecting which node represents the best carrier for the message and deciding on the optimal number of replicas to forward are both multiple attribute decision problems across all measures, where the aim is to select the node and number of messages that provide the maximum utility for carrying a certain number of messages. We achieve this by proposing a utility function that is used as measurements of relative gain, loss or equality, calculated as pair-wise comparison between the node's own parameters and that of an encountered contact. We use a pair-wise comparison matrix on the normalized relative weights of the attributes of nodes and their ego networks. As a result, our replication policy replicates at adaptively lower rates in the parts of the network that have low buffer availability, increased node delay and are likely to congest faster. As CAFREP node discovers parts of the network with higher buffer availability, lower node delays and slower congesting rates, it replicates at higher rates.

At the core of a CAFREP node is a TotalUtil heuristics (given in Formula 1) that is responsible for capturing the overall improvement a node represents when compared to an encountered node across all measures, choosing the next hop and deciding the number of copies to be sent to it so that it best manages tradeoffs across multiple contact and resource attributes of nodes in dynamic and unknown network conditions. In this paper, our SUtil(X) uses the combination of node degree centrality, tie strengths, and tie predictors as they are highly useful in routing based on local information when the underlying network exhibits a complex graph structure (this is described in more detail in [5]). RecUtil (X) and $EN_{Rec}Util(X)$ refer to the receptiveness utility of a node and its ego network respectively. RetUtil(X) and $EN_{Ret}Util(X)$ refer to node and its ego network retentiveness utility respectively. CRUtil(X) and $EN_{CR}Util(X)$ refer to node and its ego network congesting rate utility respectively. The detailed descriptions of RecUtil, RetUtil, CRUtil, $En_{Rec}Util$, $EN_{Ret}Util$ amd $EN_{CR}Util$ are given in [10-12]. We currently assume equal weights across all utilities which results in SUtil (that ranges from 0-3) weights less than combined resources utilities (that range from 0-6). As our future work, we plan to look into adaptive weighting across utilities but our work in this paper shows that even equal weights adapt well to congestion across different mobility and connectivity scenarios.

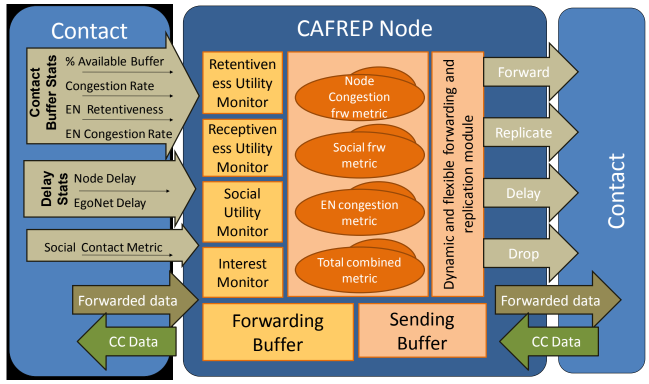

Figure 1. CAFREP

$$TotalUtil(X) = SUtil(X) + RecUtil(X) + RetUtil(X) + CRUtil(X) + EN_{Rec}Util(X) + EN_{CR}Util(X) + EN_{Ret}Util(X) \quad (1)$$

Our CAFREP algorithm functions as follows. As a forwarding node (X), meets contacts on its way, it calculates the TotalUtil of each contact on encounter. The TotalUtility helps the node X detect how well connected its contact Y is , as well as how available Y and Y’s ego network are in terms of buffer, delay and congesting rate parameters If there are multiple encounters, node X chooses the bestFit node that has the highest total utility compared to its other neighbours, and sends an adaptive number of messages to it. In order to decide on the correct number of messages, node X adjusts the replication limit *Repl-Rate* for all of its messages. If there are M replicas of a message m at node X, Equation 2 shows the formula of how we determine the number of messages that are sent to Y:

$$Repl-rate = M \cdot \frac{TotalUtil(Y)}{TotalUtil(X) + TotalUtil(Y)} \quad (2)$$

As TotalUtil of a node moves up and down, the replication limit grows to take advantage of all available resources, but backs-off when congestion increases, similar to how TCP updates its congestion window [22]. Using SUtil in the TotalUtil metric allows us to not replicate at a high rate on a node that is part of the free network but is not on the path to the destination while it allows us to replicate at a node that does not have high SUtil but has high available resources. With the use of combined adaptive forwarding and replication, we allow the sender to stop sending until it finds the right mode that it can redirect the traffic to without incurring additional packet loss. Using ego network resource utilities in addition to SUtil and node resource utilities as part TotalUtil draws on the basic DTN feature that assumes that both nodes and parts of the network can be highly heterogeneous in terms of connectivity and resource parameters. More specifically, it allows CAFREP to provide a wider view of the network resources and contacts while allowing differing local conditions. We argue that TotalUtil metric is more efficient for DTN congestion control than the metrics that estimates global congestion parameters in DTNs (such as EBR[8] and RR[21]) as it conveys information about which parts of the network are more congested than the others, and can opportunistically use parts of the network that are available while the others are busy. In this way, CAFREP enables replication at different rates at different parts of the network that can be very dissimilar from each other and thus have different social and resource characteristics and patterns.

IV. EVALUATIONS

A. *Real Data Traces: Motivation and Mobility Models*

In delay tolerant networks, the mobility of the nodes has a major impact on the performance of communication protocols. This is critical as the movement and communication patterns of peers are likely to affect the relative performance of the protocols. It is therefore fundamental to evaluate CAFREP over different mobility data sets and over realistic application scenarios. We evaluate our protocol over three different real mobility traces that have different connectivity and mobility patterns: INFOCOM 2006 [15], RollerNet [18] and DieselNet [19]. Experiments with such traces allow better characterization of CAFREP and the impact of the dynamics of the network topologies on it.

B. *Data Traces Description*

We briefly describe three different real network traces: DieselNet [19], RollerNet [18] and INFOCOM 2006 [15] that we used for our evaluation.

Haggle trace [15] consists of a 4-day long trace that is based on a human mobility experiment conducted at Infocom 2006. A total of 78 volunteers joined the experiment and each was given an iMote device capable of connecting to other Bluetooth-capable devices. In addition 20 static long-range iMote devices were placed at various locations of the conference venue; three of these were semi-static as they were placed in the building lifts.

DieselNet trace [19] consists of 20 days of traces of 40 UMass transit buses covering approximately 150 square miles. This trace contains connection events between busses as well as between buses and Access Points. DieselNet buses were subject to the schedule of the UMass campus.

RollerNet [18] dataset represents a class of DTNs that follows a pipelined shape because it has extreme dynamics in the mobility pattern of a large number of nodes. During three hours, roller-bladers travel about 20 miles, covering a large portion of Paris. Contact loggers were deployed on 62 volunteers of three types: friends of the authors, members of rollerblading associations, and staff operators. Both loggers and other participants had Bluetooth on their cell phones.

C. *Results*

We compare the performance of six protocols: CAFREP, CAFÉ[10-12], EBR[8], Retiring Replicas[21], Spray and Focus (S&F) [13] and Prophet[20] over multiple criteria in three CRAWDAD data sets:. We have built a fully distributed file casting application on the top of the forwarding protocols we are testing. Each node that has content it wants to publish, will send that content to the nodes that are interested in it and/or the nodes that "know" the nodes that are interested in it as long as they have availability. Our content is organized as in previous filecasting work [3,11]: each chunk has a unique ID and topic that contains the total number of chunks. Nodes randomly choose to be interested in a certain topic. Each node has a queue size of 1000 units. Podcasting nodes send at the rate of 5 chunks a second. For each of the three CRAWDAD datasets, we have run eight increments of congestion levels induced by increasing number of publishers first and then subscribers ranging from 1/9th to 8/9th of total number of nodes in that connectivity dataset. All simulations are repeated five times with different random subscribers and publishers. In this paper we report on experiments with increasing number of publishers due to the lack of space but note that the results for increasing number of subscribers are similar to the ones presented here.

Even though the three CRAWDAD datasets differ in terms of mobility and connectivity patterns, they all have a complex graph structure, contain nodes that differ in their centrality/importance levels and have non-uniform distribution. We show that CAFREP adapts well to the dynamics of all three datasets as it keeps high success ratio and availability, low delay and packet loss rates, and outperforms the other protocols across all datasets.

1) *Dieselnet:*

We show that CAFREP performs well within the DeiselNet dataset and always outperforms EBR, RR and other nod adaptive DTN protocols. Our scenario assumes that increasing number of randomly selected senders (ranging from 8.8% to 70.6% of the buses) are continuously sending senders to 4 (1/9th of 40) randomly selected receivers that are also buses. We assume that static access points can help with routing.

Figure 2 shows success ratio for DieselNet dataset for increasing congestion levels (induced by increasing number of senders). CAFREP achieves the best performance with close to 70% of success ratio for all congestion levels, followed by CAFÉ at 65% and RR and EBR at 60%. Prophet has low success ratio from 40% to 10% due to lack of interest points that it depends on. Spray and Focus has around close to 40% success ratio.

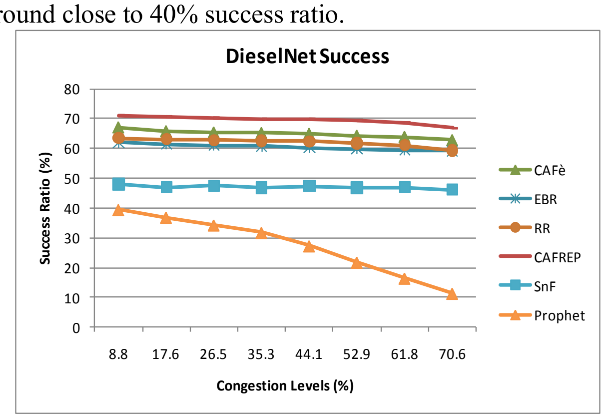

Figure 2. DieselNet Success Ratio

Figure 3 shows delays (in minutes) for DieselNet dataset for increasing number of senders from 8.8% to 70.6% senders. CAFREP achieves the lowest delays in the range of 55 to 80 minutes for increasing congestion levels, followed by CAFÉ that has delays ranging from 80 minutes to 110 minutes. RR and EBR have higher delays from both CAFREP and CAFÉ ranging from 90-160minutes and 100-180 minutes respectively. This means that EBR and RR are taking almost two or more times longer to deliver packets than CAFREP for all congestion levels. Spray and Focus and Prophet have at least three time larger delays than CAFREP.

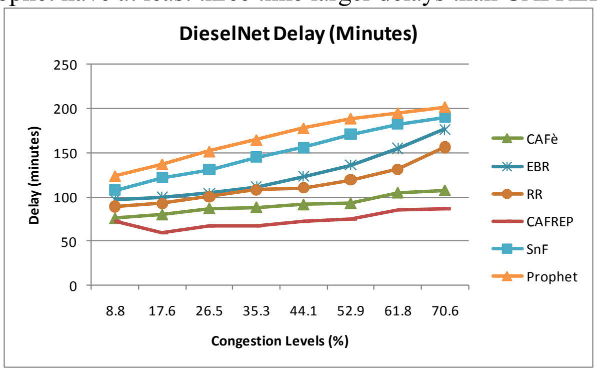

Figure 3. DieselNet Delivery Delays

Figure 4 shows availability for DieselNet dataset for increasing number of senders from 8.8% to 70.6% senders. CAFÉ has highest availability (from 90% to close to 60% for all congestion levels as it does not have replication. CAFREP maintains high node availability ranging from 80% to 30% for increasing congestion levels. CAFREP consistently outperforms EBR, RR, Spray and Focus and Prophet for medium to high congestion levels. For low congestion levels CAFREP has two times higher availability than Prophet and Spray and Focus and up to 20% higher than RR and EBR.

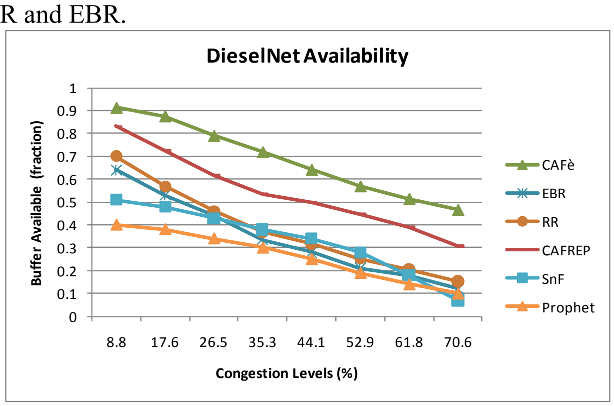

Figure 4. DieselNet Buffer Availability

2) RollerNet:

We show that CAFREP performs well within the RollerNet dataset and always outperforms EBR, RR and other not adaptive DTN protocols. Our scenario assumes that increasing number of randomly selected senders (ranging from 9.7% to 77.4% of the roller-bladers) are continuously sending senders to 6 (1/9th of 62) randomly selected receivers that are also on roller-bladers.

Figure 5 shows success ratio for RollerNet dataset for increasing number of senders from 9.7 to 77.4%. CAFREP has the highest success ration that is close to 80% for all congestion levels. It is interesting to see that RR, EBR and CAFÉ have similar success ratios in the area of 65% that is around 23% lower than CAFREP's success ratio. SF and Prophet have much lower success ration compared to all adaptive protocols, ranging from 58% to40% and 48% to 25% respectively that is close to two times less than what CAFREP achieves.

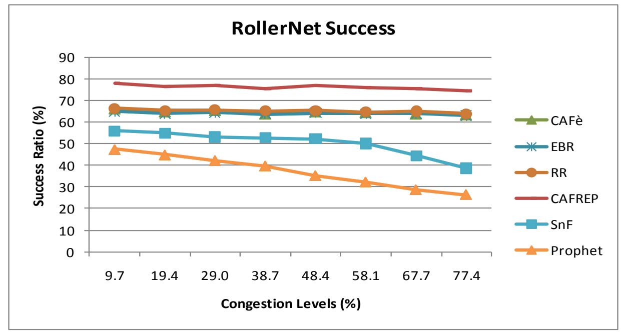

Figure 5. RollerNet Success Ratio

Figure 6 shows delays for RollerNet dataset for increasing number of senders from 9.7 to 77.4%. All adaptive protocols manage to keep 20 seconds delay for low and medium congestion levels. For high congestion levels CAFREP and CAFÉ have the lowest delay (around 28 sec) while RR and EBR increase their delays to up to two times higher delay than CAFREP. Delays for Spray and Focus and Prophet are considerably higher than for any of the adaptive protocols ranging from 30sec to 80sec (50% to 400% slower than CAFREP) and 40 to 110sec (200% to 500% slower than CAFREP) respectively.

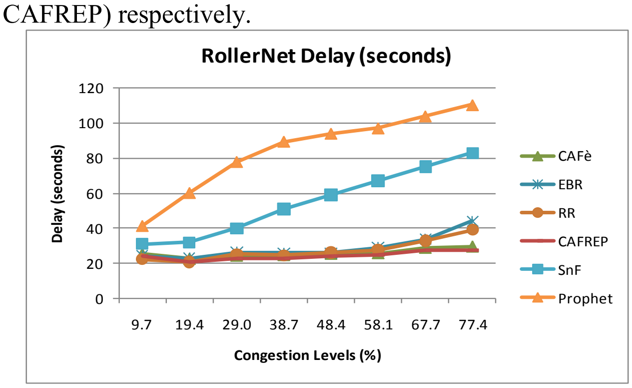

Figure 6. RollerNet Delivery Delay

Figure 7 shows node availability for RollerNet dataset for increasing number of senders from 9.7 to 77.4%. CAFÉ maintains the highest availability for all congestion levels ranging from 90% to 50% as it does not have replication. It is interesting to see that CAFREP maintains high availability ranging from 80% to 35% for increasing congestion levels and is only less than 40% lower than CAFE. CAFREP availability is persistently higher than EBR, RR, Spray and

Focus and Prophet. For low congestion levels, CAFREP is 20% better than EBR and RR and more than two times better than Spray and Focus and Prophet. For medium to high congestion levels, CAFRREP is more than two times better than all the other replication-based protocols.

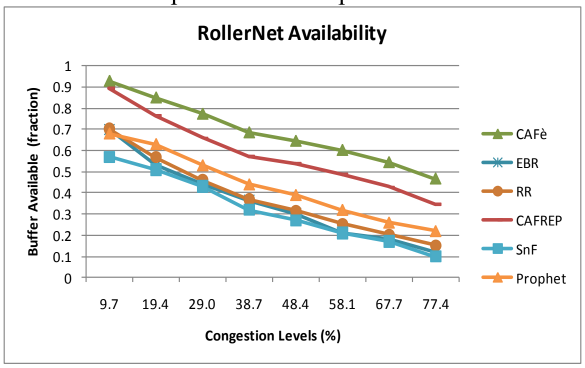

Figure 7. RollerNet Buffer Availability

3) Infocom 2006

We show that CAFREP performs well within the INFOCOM 2006 dataset and always outperforms EBR, RR and other not adaptive DTN protocols. Our scenario assumes that increasing number of randomly selected senders (ranging from 10.2% to 91%) are continuously sending senders to 8 (1/9th of 78) randomly selected receivers.

Figure 8 shows success ratio for Infocom dataset for increasing number of senders from 10.2 to 91.6%.The CAFREP has the highest success ratio ranging between 90% and 80% for all congestion levels. CAFREP success ratio is 25% higher than CAFÉ's and 30%-40% higher than RR's and EBR's respectively. Spray and Focus has over 40% lower success ratio than CAFREP. Prophet has the lowest success ratio ranging from 35% to only 10% which is more than three times lower than CAFREP for all congestion levels.

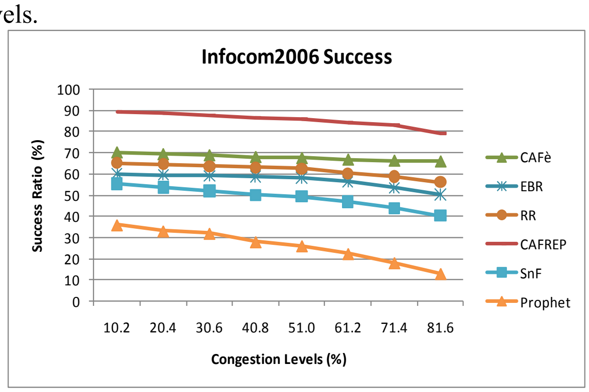

Figure 8. Infocom 2006 Success Ratio

Figure 9 shows delays for Infocom 2006 dataset for increasing number of senders from 10.2 to 91.6%. CAFREP has more than two times lower delays for low congestion rates than all the other protocols. For medium to high congestion levels, CAFREP increases delays so that it has 10% higher delays than CAFÉ. Across all congestion levels CAFREP has up to are two times lower delays than RR and Spray and Focus, and up to three times lower delays than EBR for all congestion levels. Prophet has highest delays that are persistently twice as high compared to CAFREP.

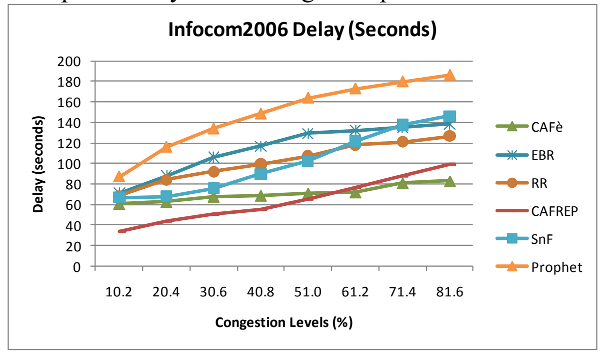

Figure 9. Infocom 2006 Delivery Delay

Figure 10 shows availability for Infocom dataset for increasing number of senders from 10.2 to 91.6%. CAFÉ maintains the highest availability ranging from 90% to 60% for increasing congestion levels. CAFREP's availability ranges from 80% to 35% as congestion increases. When compared to the other replication-based protocols, availability levels of CAFREP are up to two times higher than availability levels of RR, EBR, Spray and Focus and Prophet for all congestion levels.

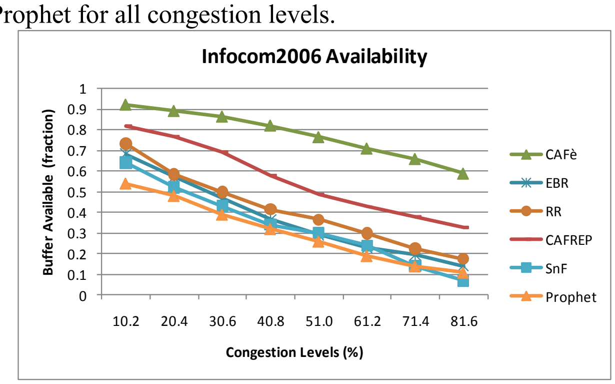

Figure 10. Infocom 2006 Buffer Availability

Table 1 shows average packet loss rates across the three CRAWDAD datasets for all five protocols. CAFREP drops 20%, 280%, 40% less packets than RR and EBR for DieselNet, Infocom 2006 and RollerNet respectively. This is due to RR and EBR not being able to opportunistically discover parts of the network with lower congestion rates but assume uniform congestion pattern. CAFREP has 45%, 300% and 78% lower packet loss rates than S&F for DieselNer, Infocom 2006 and Rollernet datasets respectively. CAFREP and Prophet have similar packet loss rates for DieselNet. CAFREP has 217% and 20% lower packet loss than Prophet for Infocom and RollerNet respectively. As expected, CAFÉ has lowest packets loss rates as it has no replication. It is interesting to see that CAFREP has lower loss rates than CAFÉ for Infocom dataset, similar for RollerNet and only 30% higher for DieselNet dataset. This is due to the fact that CAFÉ does not adjust its sending rate (and is not able to stop sending at times of high congestion) but merely redirects traffic.

TABLE I. PROTOCOLS AVERAGE PACKET LOSS RATES

	CAFè	EBR	RR	CAFREP	S&F	Prophet
DiselNet	35.1	58.7	59.8	48.7	70.6	49.6
Infocom 2006	32.1	65.2	60.4	23.0	68.1	50.9
Rollernet	35.2	52.5	53.7	37.7	66.2	43.8

Table 2 shows average number of total forwarded packets across the three CRAWDAD datasets for all five protocols. The number of total forwarded packets for CAFREP is similar to other adaptive protocols RR and EBR, and 20% smaller than for Spray and Focus. This means that CAFREP does not add additional network overhead while managing to outperform other protocols in terms of higher success ratio and availability, and lower delays and packet loss rates. Prophet has the lowest number of forwarded packets due to its lowest success ratio and availability.

TABLE II. PROTOCOLS FORWARDED PACKETS RATES

	CAFè	EBR	RR	CAFREP	S&F	Prophet
DiselNet	26657	35549	34035	33875	41998	18289
Infocom 2006	27330	35065	33974	34228	41735	17991
Rollernet	26626	35986	34457	34012	41534	20461

V. CONCLUSION AND FUTURE WORK:

We proposed CAFREP that uses a combined local encounter-based, buffer and delay metrics for congestion aware message forwarding and replication that maximizes message delivery ratio and availability of nodes while minimizing latency and packet loss rates at times of increasing congestion levels. At the core of CAFREP is a combined relative utility driven heuristic that allows highly adaptive forwarding and replication policies by managing to detect and offload congested parts of the network and adapting the sending/forwarding rates based on resource and contact predictions. We have done extensive performance analysis of CAFREP in three CRAWDAD real connectivity traces with different mobility, duration and connectivity patterns: Infocom 2006, DieselNet and RollerNet. We have shown that CAFREP outperforms four other state of the art DTN adaptive and non-adaptive routing protocols across all metrics for all data traces. We believe that CAFREP provides a useful generic and highly adaptive congestion control framework suitable for different types of resource constraint DTN application scenarios. As part of our future work we aim to work on adaptive utility weighing mechanism that would allow different weight for each utility based on the connectivity and mobility application scenario. We also plan to investigate the efficiency of CAFREP in the context of more realistic anycast and multicast applications.

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