Reliability Trade-off Analysis of Deadline-Sensitive Wireless Messaging Systems

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Abstract

The need for deadline-sensitive messaging systems is growing fast with the growth in the number of mobile and static devices communicating with each other. With many such devices from different locations exchanging messages over a network, understanding the reliability of message delivery so as to cost-effectively improve it becomes challenging. The analysis is even more challenging and complex when some or most of the nodes are moving at different speeds following different mobility patterns and when the network is wireless. In this paper we present a reliability trade-off analysis for the exchange of messages between nodes under different mobility scenarios and various parameters using simulation. Some of the nodes in our study are message servers which are responsible for the control and delivery (relay) of messages from one client node to another client node.

Among other things, our simulation results show that a message reliability of greater than 75% can be obtained using a method of smart server selection and more servers or a higher transmission range if the servers are not moving. However with a method of random server selection or if servers are moving a 75% message reliability cannot be achieved even using more servers and a higher range. The higher the packet sending rate by the clients, the higher the file reliability (specially for bigger files and smaller transmission ranges). For chat messaging, the reliability usually increases as the speed of the nodes (clients) increases.

I. Introduction

In recent years, we have seen an ever growing number of devices networked with each other to exchange messages. The need for efficient deadline-sensitive messaging protocols and algorithms increases accordingly. Even though there are many categories of messaging and presence protocols (IMP), in this study we focus on Extensible Messaging and Presence Protocol (XMPP) [8], which is an open standard. The other related open standard protocol is the Session Initiation Protocol (SIP) for Instant Messaging and Presence Leveraging Extensions (SIMPLE) [7]. The XMPP architecture is a lightweight protocol with fewer RFCs and higher market penetration. It is used in the Gtalk application by Google for instance. Besides, XMPP allows inter-working with proprietary protocols using its Gateway. Hence, we will analyze the XMPP-like approach in this paper. In the XMPP protocol, all senders and receivers register at their respective controller (server) with their names or IDs. A server broadcasts presence information of the subscribed clients to all clients and other servers. A client then creates its roster by getting subscription approval from other clients. A client can then send messages to its respective peer. A moving client can subscribe to the nearest server (smart selection) which can route its messages to the intended receiver.

Deadline-sensitive messaging systems (DMS) include publish/subscribe [4], instant messaging (IM) and presence protocols (IMP) [8] and file exchange systems[5]. In the case of publish/subscribe or file transfer systems some of the nodes are senders (publishers) and some others are receivers (subscribers). In the case of IM or IMP protocols a node can be both a sender and a receiver. In the case of IM and IMP protocols as well as publish/subscribe systems messages are usually small in size and can fit into a about 1500 byte packet. File transfer protocols, on the other hand, involve sending multiple packets.

Such protocols and algorithms cannot be efficiently designed and upgraded without a proper analysis and understanding of the behavior of the nodes communicating using such protocols under different mobility scenarios. Simulation is one of the important tools to help design, analyze and improve such protocols. Previous study [6] has made extensive analysis of pub/sub systems. But only for mobile subscribers as publishers and servers are usually static. A Reliability Calculus to analyze communication reliability has been presented in [3]. In the paper the authors focus on the delay distribution of control messages or feedback signals. They use a calculus based on frequency domain analysis of communication reliability (end-to-end delay distribution). However, this study doesn't give a trade-off analysis of reliability with varying numbers of parameters such as number of servers (base-stations), transmission range and mobility scenarios. A probabilistic measure of broadcast reliability called Δ-Reliable Broadcast is presented at [1]. This paper makes a stochastic analysis assuming that failures are stochastically independent. This implies that the analysis excludes dependent communication failures due to lack of base-station coverage in a given cell of the coverage area. In other words, dependent link failures like a network partition are outside of the failure model.

In this paper we focus on the study of IM and IMP protocols as well as file transfer between nodes where any of the DMS nodes can be mobile. An important quality of service (QoS) metric to study the performance of such protocols is the reliability, R of message delivery. For instance it can be very costly to use many servers (base stations) even though full coverage and very high reliability can be obtained by using such an approach. Besides, a 100% reliability of message delivery may not be required by many applications. For instance multimedia applications can tolerate some packet losses. On the other hand communication with a very poor reliability of message delivery can be of no use. Hence we study the reliability as a function of many parameters.

In our analysis some of the nodes are clients which exchange messages among each other and some of the nodes are servers which help the clients exchange information. We considered different mobility scenarios for these nodes.

We also present a server selection scheme which increases the reliability of message delivery. In this scheme the server, which last sent a beacon message rather than a random server in the sender's server list, is selected by a sending node. Among many other things our analysis shows that a message reliability of greater than 75% can be obtained using a method of smart server selection and more servers or a higher transmission range if the servers are not moving. However, with a method of random server selection, or if servers are moving, a 75% message reliability cannot be achieved even using more servers and a higher range.

This rest of the paper is organized in such a way that section II describes the message exchange system model we analyzed. We then present the problem statement in section III, some numerical results in section IV, the conclusion in section V.

II. System Model

This section describes the model and architecture of the system we analyze. The architecture consists of nodes, the network and the information the nodes want to communicate with each other over the network using message delivery protocols in a one way or two way communication. We next discuss each of these components of the system.

Node Model: DMS usually involve entities (clients) and servers which help the entities communicate. So our node model is comprised of n_s servers and n_c entities (clients). An entity can be a sender, a receiver or both. To study sending and receiving behaviors of nodes, we experiment with controlled environments, where we have n_c^s senders and n_c^r receivers.

Information Model: In this paper we focus on the study of IM and IMP protocols as well as file transfer between nodes. In our study we considered unreliable transmission of packets using a protocol similar to the User Datagram Protocol (UDP). We next present protocols used to deliver both short (chat) and big (file) messages.

Message Delivery Protocols: An XMPP [8] like protocol is used for the instant messaging (IM) and presence protocols (IMP) [8] and file exchange systems[5] analysis we make in this paper.

Network Model: The communication between the clients and the servers can be in 3G, 4G, or WiFi. In this study we use the WiFi communication between the clients and the servers. The communication between the servers can be wired, 3G, 4G or even WiFi. In most of our analysis the communication between the servers is over wired links. We also have an analysis where the communication between all nodes is WiFi.

Communication Model: For chat messages the communication between the clients (entities) is many to many as each client may want to chat with many other clients in a two way communication. The file transfer messaging on the other hand is usually one way with one client transferring file chunks to another client in a one way communication.

Evaluation Metric: In this study we evaluate the performance of the messaging protocols under different network and mobility scenarios using a reliability metric. The reliability R of message delivery is obtained in terms of the number of packets generated G and the number S of packets received by the intended node as

$$R = \frac{S}{G}. \quad (1)$$

The file reliability R_F is defined as follows:

$$R_F = \frac{S_F}{G_F}. \quad (2)$$

Where G_F is the total number of a files generated for all receivers and S_F is the total number of files successfully received by all intended receivers and obviously $S_F \leq G_F$. We obtain the file reliability using an all or none approach in which case the reliability of a file is 0 even if only one packet of the file is lost. This definition of file reliability can be relaxed to tolerate some packet losses before assuming the file is lost.

III. Problem Statement and Proposed Approach

We evaluate the reliability R of message delivery as a function f of the length l and width w dimensions of the rectangular movement area, the wireless transmission range t, the number n_s of servers or controllers (base stations), message deadline d, the number n_c of clients exchanging messages in the area, average client speed v, mobility scenario M, server selection method S, beacon interval B of the wireless nodes, packet generation interval i and file size s. We observe how the function

$$R = f(l, w, t, n_s, d, n_c, v, M, S, B, i, s) \quad (3)$$

varies with the varying values of each parameter while keeping the other parameters constant using simulation. We also observe how the function changes when a combination of some of the values of the parameters changes. Such trade-off analysis gives a good understanding of how much of each parameter is needed to achieve a desired reliability of message delivery.

IV. Trade-off Analysis

In this section, we first discuss the environment we use for our trade-off analysis. We then present the trade-off analysis as a function of many parameters.

Analysis Environment: We evaluate the XMPP like messaging system via simulations using NS2 [2] simulator under different network and mobility scenarios. Figure 1 shows a sample scenario for our simulation. In this figure, S represents sender node, R represents receiver node and C represents session controller (server) nodes.

In our study we have made the following assumptions.

- Every communication passes through the servers (controllers). Messages are stored at the servers until their receivers come in range or until they expire. This is the typical case in today's messaging protocols.
- Every message sent is replicated at all servers from any of which a receiver gets.
- Discrete mobility speeds range from 5 to 50 m/s with an interval of 5.

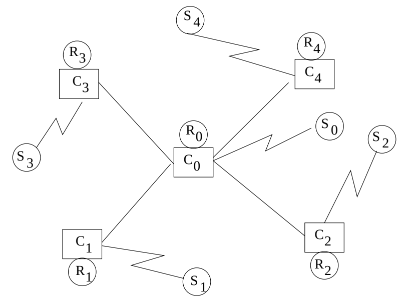

Fig. 1: Evaluation Scenario

- We consider the following two different server selection methods.
  1) *Naive random server selection* where a sending node chooses any of the servers from the list of servers it received beacon messages from.
  2) *Smart server selection* where a sending node selects the last server it received a beacon message from.

We have used a star-topology as shown in Figure 1 for our experiment. Our choice of this topology also conforms with the centralized nature of messaging systems, even though any other topology with any routing protocol can be used. The values of the simulation parameters used to evaluate the reliability function f shown in Equation 3 are given in Table I.

TABLE I: Simulation Parameters

Parameters	Values
n_c	15 - 29
$l \times w$	1000m x 1000m
n_s	5 servers, 9 servers
S	naive selection, smart selection
t	150m, 250m
M	Manhattan Mobility Model
v	1 - 50 meters/sec
d	60 s
b	0.1 s
i	0.1 s and 0.5 s
s	3 pkts and 10pkts

Our trade-off analysis simulation results are organized as follows:

- Case 1: R Versus t
- Case 2: R Versus t and n_s
- Case 3: R Versus t, n_s and S
- Case 4: R Versus t, n_s and i
- Case 5: R Versus t, n_s and s

Unless otherwise specified, the results in this section are for a fixed packet size of $24 + IPHDRLEN$ Bytes, where $20 \leq IPHDRLEN \leq 60$.

Case 1: Figure 2 shows the results of the scenario where receivers (subscribers) are mobile and all other nodes are static. Here we see that, even for 150m communication range, the file reliability is higher especially when the receiver speed is very high. The fact that the senders are not moving improves the reliability. Here it must be noted that the server selection by senders has no effect as the senders are not moving. When the receivers move faster the reliability improves as the moving nodes can quickly come closer to the servers before the message deadline expires. This conforms to some interesting results [9] in the literature that mobility improves capacity.

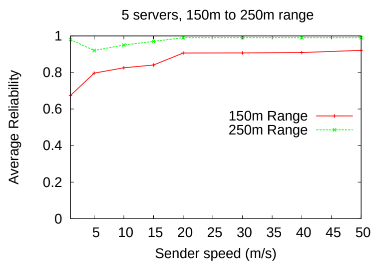

Fig. 2: Mobile senders (subs): 1-to-many, chat, $n_s = 5$

Figure 3 shows the results for the scenario where both senders and receivers are moving and only the servers are static with a random server selection. Here, we see that, even for 250m wireless communication range and higher speed, the maximum average reliability is very small. Here the combination of random server selection and receiver mobility causes a very small average reliability.

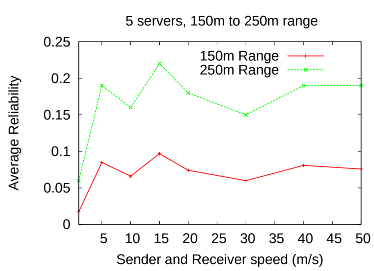

Fig. 3: Mobile senders (pubs) and receivers (subs): $i = 5$, 1-to-many

Figure 4 shows the result for reliability where all nodes (sender, receiver, and servers) are mobile. Here we see that, even for our best cases (9 servers, 250m wireless range and smart server selection), the reliability is very small. When all the nodes are moving, the network may be segmented into smaller isolated networks. In this case if the sender is in one segment and the receiver is in another segment which is out of range of the sender's server segment, then it becomes difficult to transfer messages between the nodes. We are working on ways to improve the reliability for this scenario.

Case 2: Figure 5 shows the reliability results for 1-to-1 chat communication where only the senders are

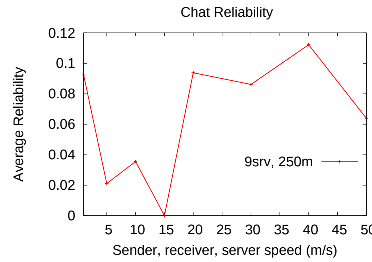

Fig. 4: All nodes mobile $n_s = 9, t = 250, s = 3$: Chat

moving. Here, we consider 5 senders, 5 receivers and 5 topics. The chat message is generated at a uniform rate of $1packet/5sec$. From the figure, we see that, this scenario gives almost 100% average reliability with 9 servers and 250m wireless transmission range. As can be seen from the result, the reliability is the smallest with a 150m transmission range and 5 servers.

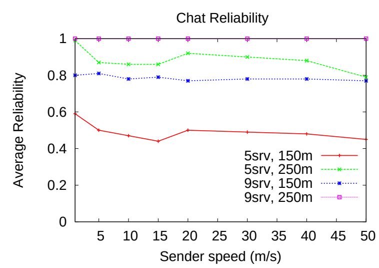

Fig. 5: Mobile senders (publishers): 1-to-1 chat

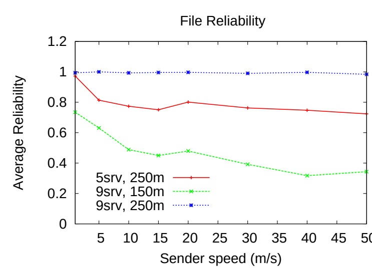

Fig. 6: Mobile senders: $i = 5, s = 10$

Figures 6 shows the reliability results for file transfer scenario where only senders are mobile and all other nodes are static. We consider 5 server case along with 5 senders, 5 receivers, 5 topics and 9 server case along with 6 senders, 18 receivers, 6 topics. We also consider that the file packet size is fixed to be $1000+24+IPHDRLEN$ Bytes where $20 \leq IPHDRLEN \leq 60$ and file packet is generated at a uniform rate $10pkt/5sec$. We have used smart server selection and more servers. From the figure, we see that, these scenarios give almost 100% average reliability with the 250m wireless transmission range and 9 servers.

Case 3: Figure 7 shows the result for 1-to-many chat communication scenario. In this case, again we see that, the 9 servers and 250m case, along with smart server selection, provides the best result. The result clearly shows the benefits of a sender's smart server selection over the random selection.

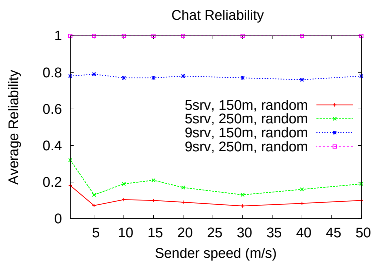

Fig. 7: Mobile senders (publishers): Chat $i = 5$, 1-to-many

Case 4: Figure 8 shows the reliability results altogether to understand how packet generation rate i which we also call publication rate $(pint)$ impacts the file reliability results. As can be seen from the results, higher packet generation rate improves reliability. This is because with higher rate, more packets are transmitted before a node moves out of range. The improvement is even higher when the file size is bigger (see Figure 9) and the transmission range is smaller. With a higher transmission range and enough servers there is enough coverage that the packet generation rate doesn't matter that much.

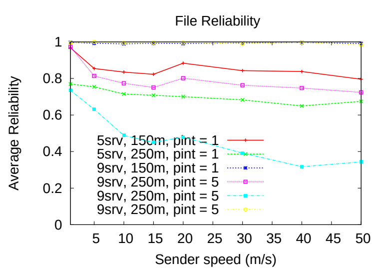

Fig. 8: Mobile senders (publisher) $i = pint, s = 10pkts$

Case 5: As can be seen from Figure 9, the smaller the file size the better the file reliability. One reason for this may be that there are more chances for a bigger file's reliability to be 0 as bigger files contain more packets and as any one packet loss means the whole file is lost.

V. Conclusion

In this paper, we present a reliability trade-off simulation analysis of a deadline-sensitive messaging systems (DMS) in mobile networks. Our analysis shows that unless servers are static and smart server selection is used DMS

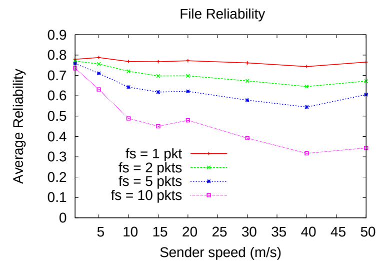

Fig. 9: Mobile senders: $n_s = 9, t = 150m, i = 5s$

in mobile networks are not feasible. For example for a 1000m x 1000m coverage area, a random server selection results in reliability which is less than 25%. For the same area if servers are moving, the reliability becomes less than 12%. On the other hand any mobility speed of 1m/sec to 50m/sec of clients can be tolerated with sufficient number of static servers and transmission range using smart server selection. A 150m range with 9 servers or 5 servers with 250m range gives a chat message reliability which is higher than 75%. For the same coverage area only a 250m transmission range gives a file reliability greater than 75%. Higher packet generation rate also improves file reliability specially for bigger files and smaller transmission ranges. The reliability of chat message delivery usually increases as the speed of the nodes increases. This conforms with some findings [9] in the literature.

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