# Supporting Group-oriented Mobile Services

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## Abstract

The emerging mobile services, including mobile commerce, have received considerable interest among researchers, developers, service providers, and users. Some of these mobile services will require the support for group communications among mobile users. An efficient way to support this requirement is using wireless multicast, where group connectivity among users is maintained and the information exchange is performed by the underlying networking infrastructure. In this paper, the multicast requirements of group-oriented mobile services under varying levels of connectivity are addressed. More specifically, the design and operation of three protocols for supporting multicast transactions are presented. Since these protocols could lead to different response time and transaction completion probabilities, a detailed performance evaluation under different connectivity and conditions has been performed. It is shown that a range of transaction completion probabilities and transaction delays can be achieved to support the performance requirements of diverse group-oriented mobile services.

Keywords: mobile services, mobile applications, group communications, wireless multicast, multicast protocols, performance evaluation, analytical modeling, transaction, and connectivity

## 1. Introduction

Many of the emerging mobile services are likely to be group-oriented, where either the same information is sent to several users or multiple users have to simultaneously interact to reach an outcome. Some examples of group-oriented mobile services are mobile auction, mobile financial applications, mobile advertising, mobile office, mobile entertainment, and multiparty games [1]. The group communications requirement of these applications can be efficiently supported by using multicast, where messages are exchanged among group users simultaneously using one to many or many to many connections [2]. As mobile users move to different locations or leave the group or new users join the group, the membership information has to be updated for network traffic routing [3-7]. There are many challenges that must be overcome in wireless multicast to support group-oriented mobile services. One such challenge is how to support group-oriented transactions in an environment where mobile users experience brief dis-connectivity and/or intermittent connectivity. This becomes even more complex due to variable, limited and asymmetric resources combined with possibly dynamic topology of ad hoc wireless networks.

A significant amount of research has been done on addressing the routing operation of multicast protocols or modifying the existing unicast routing protocols to support multicast. This includes protocols such as AMRIS [8], AMRoute [9], FGMP [10], ODMRP [11], SPINE [12], CAMP [13], AODV [14], DSR [15], MCEDAR [16], and asymmetric satellite-based multicast [17]. The use of flooding to support reliable routing is proposed in [18]. Some guidance on multicast routing can be found in [19] and detailed comparison of several routing protocols is performed in [20-22]. Some recent work on multicast includes the design of efficient routing protocols [23], support for multicast in wireless LANs [24], extending ODMRP for multi-hop wireless networks [25], designing energy-efficient routing protocols [26], supporting error control in multicast [27], and providing security for mobile multicast [28].

So the most of the multicast work deals with membership management, routing, and to some extent security. Although these are important aspects of wireless multicast, mobile services will be benefited significantly if a multi-layer approach is employed where application, middleware and networking issues are addressed together. In this paper, we address how to support group-oriented transactions for mobile services using multicast protocols and characteristics of applications. A transaction can be considered as a unit of work where all steps are necessary in an ordered sequence. A group transaction could involve multiple components as shown in Figure 1. For example, a user wants to initiate a mobile transaction. Such request will be forwarded to a transaction server. Then a multicast session will be initiated with the help of a multicast server.

The transaction could also require accessing data center and the services of third party (not shown here). Also the duration of multicast session is dependent on the mobile application. For example, mobile advertising only needs to send one or more messages to users. As users experience brief dis-connectivity or intermittent connectivity, the transaction performance could become unacceptable for some group-oriented services.

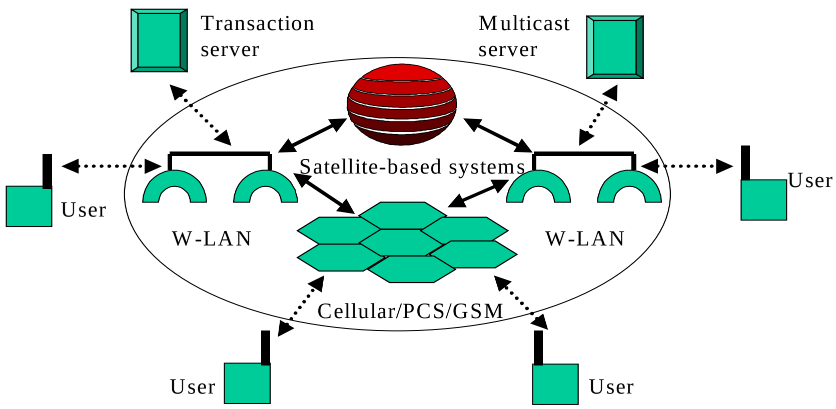


**Figure 1. Group Transactions for Mobile Services**

If the mobile services have to run in ad hoc wireless networks with mobile nodes in dynamic topologies, then the impact of brief dis-connectivity or intermittent connectivity could even be higher. This would adversely affect the performance of many group-oriented mobile services. In such an environment, one of more nodes (devices or servers) could be dynamically selected to act as group leaders based on their ability to locate one or more required servers. Since users, devices, networks, and servers could all be mobile, completing a series of transactions using a multicast session before one node moves out of the range will become a challenging task. Fortunately, many of the group-oriented transactions could be of short duration, thus could be completed before a user moves to another location. It is possible to use (slow) mobility level in selecting group leaders and servers for mobile transactions. For additional functions, one or more nodes would require connectivity to other servers using one or more additional wireless networks such as satellite or overlapped cellular networks. It is also possible that group-oriented mobile services use a combination of infrastructure and ad hoc wireless networks.

We believe that ours is the first such study that addresses how to support multicast requirements and transactions for group-oriented mobile services under brief dis-connectivity or intermittent connectivity. The major contributions of this paper: (a) identification of the requirements of group-oriented mobile services, (b) design of three multicast protocols to support group communications under brief dis-connectivity and intermittent connectivity, and, (c) development of an analytical model for evaluating the performance of the proposed multicast protocols. In addition to these important contributions, the paper also presents several new metrics and parameters for measuring the performance. These metrics could also be used to evaluation and comparison of future protocols. Using the analytical model, the results show that brief and intermittent connectivity of mobile users adversely affects transaction completion probability. One interesting result of our research also shows that flexible and adaptable group-oriented mobile services can achieve a higher percentage of transaction completion. It is also shown that a range of transaction completion probabilities and transaction delays can be achieved to support the performance requirements of diverse group-oriented mobile services.

The paper is organized as follows. In section 2, several group-oriented mobile services and their specific requirements are presented. Then in section 3, the design of three multicast protocols is presented. Performance metrics and protocol issues are discussed in section 4 and the performance evaluation using analytical model is presented in section 5. Finally, some concluding remarks are made in section 6.

## 2. Group-oriented Mobile Services

The group-oriented mobile services could include Mobile Auction, Mobile Games, Mobile Financial Services, Mobile and Locational Advertising, Mobile Entertainment Services, Mobile Distance Education, Proactive Service Management, Product Recommendation Systems, Mobile Inventory Management, and Product Location and Search. Some of these services are illustrated in Figure 2 and more details can be found in [1]. The focus here is to derive the requirements of these mobile services by classifying services with similar requirements in a group. This classification would reduce the complexity of requirement analysis and will also help in modeling and performance evaluation. The criteria used were the type of communications, number of entities, response time, and connectivity requirements (Table 1). It should be noted here that this is not an exhaustive list of group-oriented mobile services, however any current and emerging mobile service can be added to this classification with little additional effort. We believe that by deriving general requirements of group-oriented mobile services, better protocols can be designed and deployed.

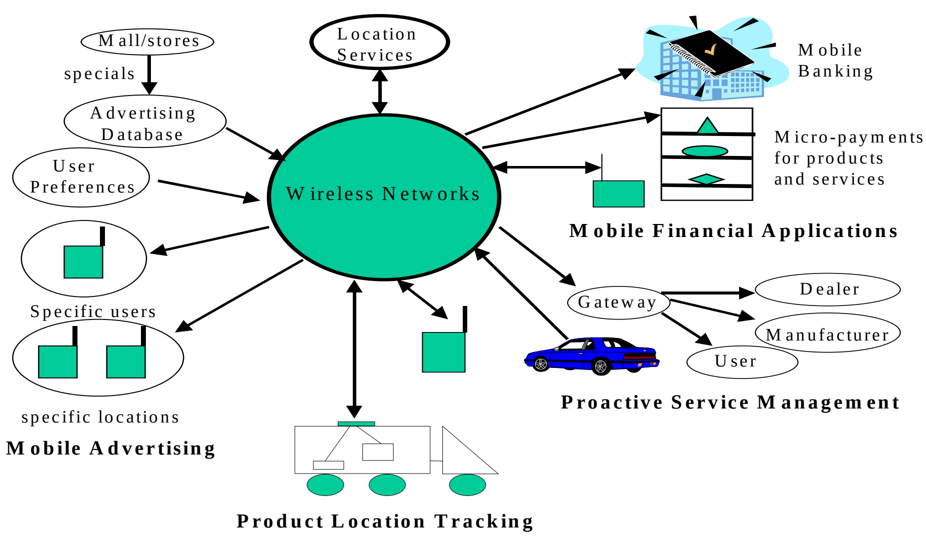


**Figure 2. Few Group-oriented Mobile Services**

**Table 1. Group-oriented mobile services and requirements**

| Group-oriented Mobile Services | Description | Type of communication and number of entities | Multicast requirements and response time |
|---|---|---|---|
| Mobile Auction, Interactive Games, Financial Services | Users to buy or sell certain items, play multiparty games, conduct multi-party financial transactions | Real-time multicast with active participation from multiple users | Very low delays<br>Continued connectivity required |
| Mobile and Locational Advertising | Applications turning the wireless devices into a powerful marketing medium | Asymmetric non-real-time multicast involving hundreds or more devices | Higher delays can be tolerated<br>Intermittent connectivity or brief disconnectivity may be tolerated |
| Mobile Entertainment Services/Mobile Distance Education | entertainment or distance education services to users on per event or subscription basis | Asymmetric Real-time Multicast involving multiple users | Large bandwidth and low delays<br>Intermittent connectivity or brief disconnectivity significantly affects the overall experience. |
| Proactive Service Management | Providing users the information they will need in very-near-future | Asymmetric non-real-time multicast involving a few entities | Higher delays can be tolerated<br>Intermittent connectivity or brief disconnectivity can be tolerated |
| Product Recommendation Systems | To receive recommendation on products & services from a 3rd party or customers | Asymmetric non-real-time multicast involving large number of entities | Higher delays can be tolerated<br>Intermittent connectivity or brief dis-connectivity can be tolerated |
| Mobile Inventory Management/ Product Location | Reducing the inventory by managing in-house and inventory-on-move/to find the location of product and services | Unicast/Multicast involving few entities | Response time of few seconds<br>Intermittent connectivity or brief dis-connectivity increases the delay |

From Table 1, it is clear that group-oriented mobile services present diverse set of requirements where some services need real-time multicast while others could be supported well even if the delays were higher. The impact of brief dis-connectivity and/or intermittent connectivity also varies substantially among these mobile services. If these connectivity problems result in aborting a transaction, then it could lead to waste of resources.

## 3. Protocols for Supporting Group Communications

A group transaction could involve several mobile users, who could experience brief dis-connectivity and/or intermittent connectivity as on-off periods. It is possible that for some mobile users, there is some co-relation among the periods of disconnections (facing similar problems in a location at a time), however, we assume that each user experiences connectivity problems independently of other users (Figure 3). Our future work would address situations where multiple users exhibit co-related periods of dis-connectivity or intermittent connectivity.

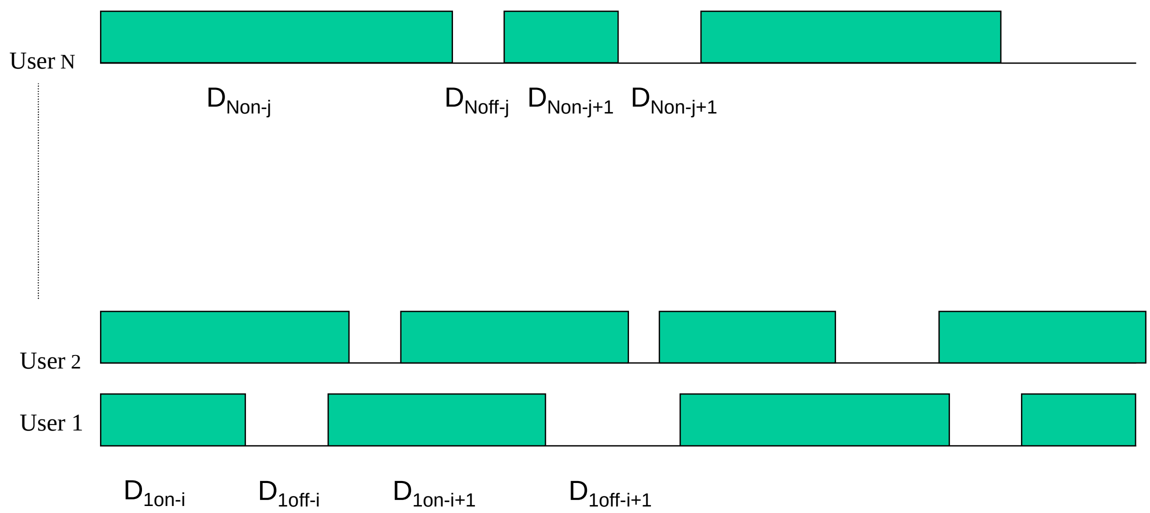


**Figure 3. Connectivity and Dis-connectivity for Mobile Participants**

Although the requirements of group-oriented mobile services could vary considerably, for a general case we assume a three-stage sequence: pre-processing, inputs from users, and post processing. The pre-processing stage could involve service advertisement and discovery, joining of members and setting up of rules and regulations. The impact of dis-connectivity would differ considerably among these stages of group-oriented services. For example, brief dis-connectivity and/or intermittent connectivity could be tolerated during post-processing stage while such events would affect the application and its performance significantly during stage 2.

The user mobility and wireless link characteristics could make the continuous communications among group users difficult. This would affect the performance and outcome of group-oriented mobile services such as mobile auction, games, and financial services where user participation is important. No response from a certain user for some time could lead an ambiguity about the user leaving the group or experiencing a brief dis-connectivity. If there is a reason to believe that user is experiencing connectivity problems, then the state of the application could be maintained until a time-out occurs or the user sends some information again. On the other hand, if the user response could not have affected the outcome of the group application, then it would be wasteful for everyone in the group to wait for this user. Such determination could be difficult for all possible states of group-oriented mobile services.

In supporting group-oriented transactions, one major issue is the determination of the reasonable time to wait for response from mobile users. As time-out is a possible technique for group management (remove a user from the group application if do not hear anything for a given time) in such applications, the value of time-outs could affect the performance of group-oriented mobile services. If a smaller value is chosen, it will lead to frequent removal of mobile users from the group when experiencing a brief dis-connectivity. Later on, these users could attempt to connect to the group but since the state of application will likely to have changed significantly (such as bidding in a mobile auction), these users would have lost the chance to affect the outcome of the group application. On the other side, if a higher value of time-out is chosen, then all the connected users are forced to wait for these users who are either experiencing significant connectivity problem or have been permanently disconnected. This will also reduce the performance (speed) of mobile services for most users. To avoid these extremes, finding an optimal or near optimal time-out is necessary for achieving a high level of performance from mobile applications for most users. The value of time-outs could affect the transaction completion probability and transaction response time.

We have designed three protocols for supporting transactions in group-oriented mobile services (Table 2). These are named UW (unlimited wait), LW (limited wait) and SBW (status-based wait) using their basic operation technique. The mobile services that could tolerate larger response time would work better with UW due to its simplicity and less overhead, although it has no upper bound on delays. The mobile services requiring lower delays will benefit from LW or

SBW. These protocols would also result in different levels of transaction completion probabilities and response times. A basic operation of these protocols is illustrated in Figure 4.

**Table 2. Major Steps of Three Protocols**

| Protocol | Description | Comments |
|---|---|---|
| **1:** all users equal & unlimited waiting (UW) | If no input from a user, wait until the user responds or sends a leave message | Simplest to implement<br>Likely to work well for transactions with tolerance for higher delays<br>Likely to have the least affect of brief dis-connectivity or intermittent connectivity (highest probability of transaction completion) |
| **2:** all users equal & limited waiting (LW) | Step 1: If no input from a user, wait only for the predetermined time<br>Step 2: If transaction needs the user, block the group transaction | Simple to implement<br>Likely to work well for transactions with lower delay requirement<br>Likely to have the effect of brief dis-connectivity or intermittent connectivity (reasonable probability of transaction completion) |
| **3:** Status-based waiting (SBW) | Step 1: If no input from a user, wait for certain time based on the type of user<br>Step 2: If transaction needs the user, block the group transaction | More complex to implement<br>Likely to work well for transactions with lower delay requirement<br>Could lead to a more optimal combination of response time and transaction completion probability under intermittent connectivity |

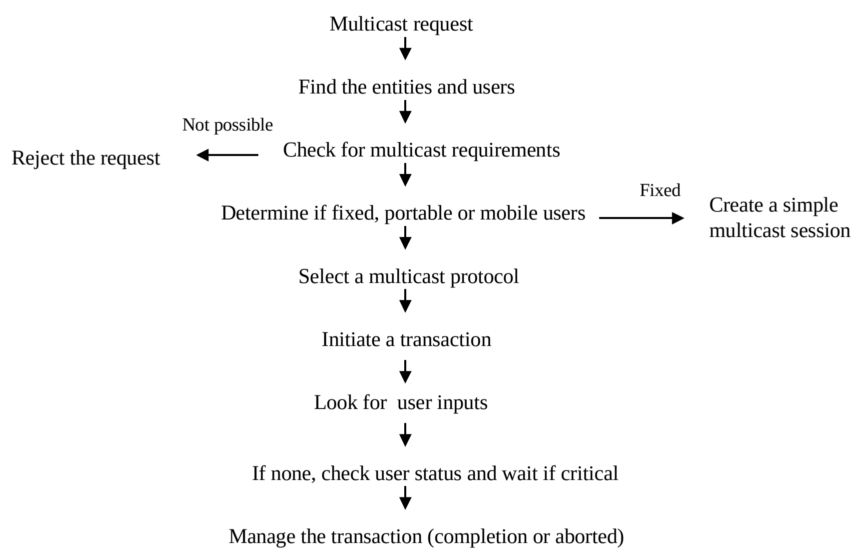


**Figure 4. A step-by-step description of multicast process**

The impact of three protocols combined with intermittent and brief dis-connectivity is shown in Figure 5, where different layers of a wireless network are illustrated [7]. For UW, the group is forced to wait until the user sends an input. LW involves waiting only for some time as determined by previous values and/or using information on brief dis-connectivity. In SBW, the group waits for different time based on the type of user: passive listener, active listener, and active participant. For the first type, the user can be removed from the group and can join later without affecting the status of the group. For the second type, the group can wait for some time, however for the third type of users, the group should wait longer as the input from such users can affect the outcome of the group application. Then a trade-off can be done between overhead due to the continued information transmission to users who may no longer be members (larger time-outs are used) to the overhead of join operation later (if smaller time outs are used).

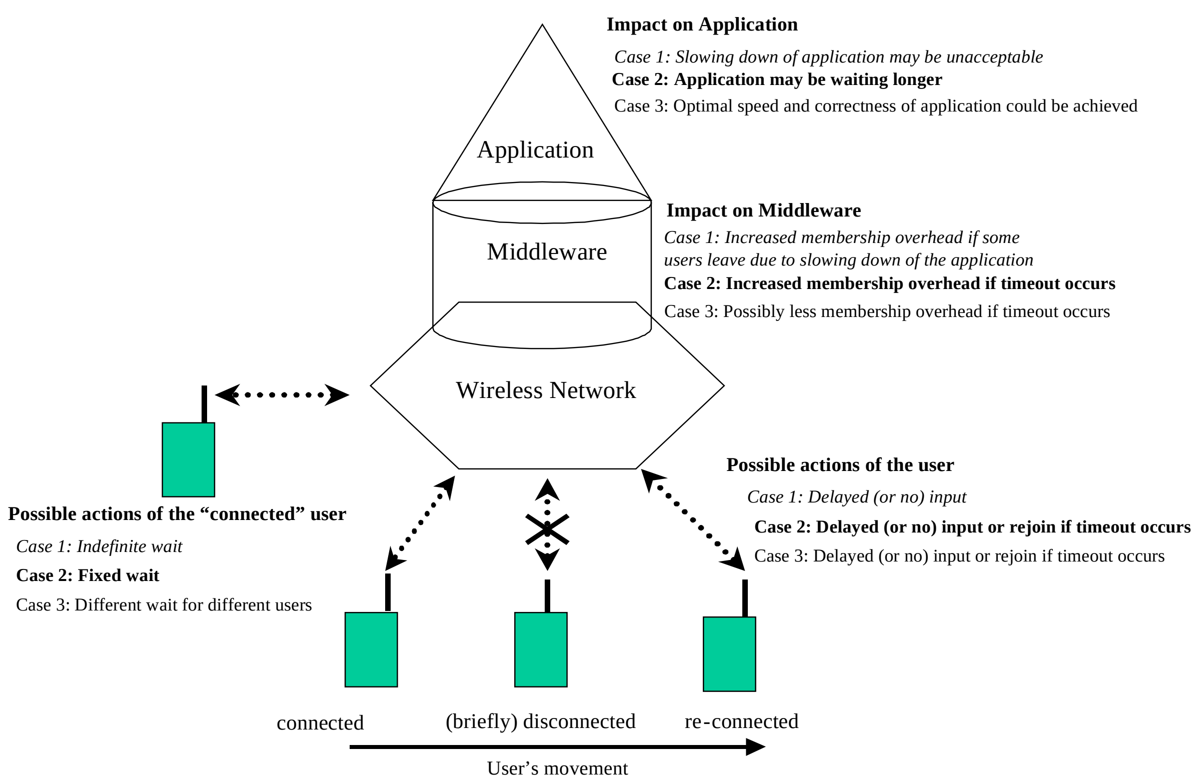


**Figure 5. Impact of Three Protocols on Different Layers**

The group-oriented mobile services can be modeled using multiple stages and varying number of participants involved in each stage (Figure 6). It should be noted that the number of such stages would differ substantially among different mobile applications and the inter-dependency of stages could vary significantly among applications. The lack of input from a certain user in a stage could affect one or more inputs in the next stage, thus possibly resulting in a different outcome of the application. It could be possible to identify both the number and actual "critical" users whose response in stages would be sufficient for the correctness of application. Thus the waiting for these users can be differentiated from other "non-critical" users in case of delays. The number of stages in an application could be chosen by the total number of users, minimum and maximum number of users per stage, delay tolerance per stage, processing delay per stage, and the total transaction delay required. It would be better to have fewer stages, but then an increased number of highly mobile users in a stage could increase the waiting time (thus delay). Using these and inter-dependency constraints, group-oriented applications can be broken into a certain number of stages, each with some number of users to achieve a certain delay. The current connectivity of mobile users could be used in determining the number of stages.

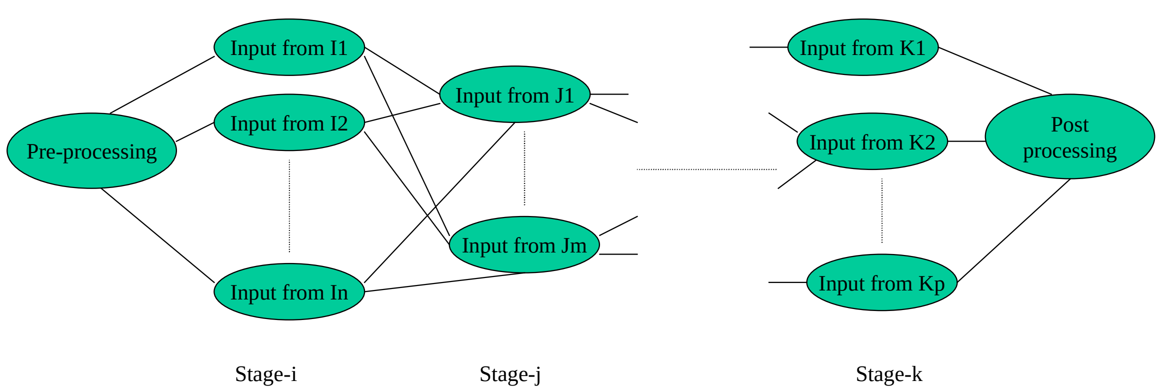


**Figure 6. Stages and Participants in Group Applications**

## 4. Performance Metrics and Additional Protocol Issues

Since there has been little work in group-oriented mobile services, it is difficult to characterize the performance of protocols using any existing metrics. To facilitate research in the performance of group-oriented mobile services, we define several new parameters. The first is Entity to Transaction Ratio (ETR) for defining the number of entities involved in a transaction. A higher value of ETR is likely to increase the wait and thus would result in an increased response time or a lower transaction completion probability in a given time. Another parameter is Mobile Member Ratio (MMR) for defining the fraction of users that are highly mobile or experience frequent brief dis-connectivity. The value of MMR could vary over a range and is affected by both user mobility and characteristics of wireless links. The effect of high MMR would be more on services that require real-time multicast (low delays) as the system would have to wait longer for mobile users or abort the transactions. The Transaction to Mobility Product (TMP) can be defined as the product of average transaction length and mobility (which in turn is the product of avg. length and frequency of disconnections). As some transactions could be very long, leading to a higher TMP. The value of TMP could be higher if mobile users experience longer or more frequent connectivity interruptions. From a performance point-of-view, lower the TMP, higher is the chance of transaction completion. The Transaction to Session-length Ratio (TSR) defines the number of transactions in a unit of time during a multicast session. The Source to Members Ratio (SMR) defines the fraction of users in a session that could act as source of multicast transaction, if needed. This would be dependent on the type of mobile services and a high value will affect the performance negatively, as more sources will increase the frequency of larger wait under connectivity problems. However, a higher value of SMR would also lead to a more dependable support for group transactions that could be conducted even after the failure of one or more sources. In addition to performance metrics, there are many issues that must be considered for the proposed multicast protocols, UW, LW and SBW. These include flexibility, granularity, dependability, adaptability, and effects of network congestion.

Flexibility can be specified as the minimum number of users that remain to be connected for the transaction to continue. A high level of flexibility from group-oriented application would result in reduced delays for all three protocols and improved transaction completion probability for LW and SBW protocols. This would also result in a reduced number of re-attempted transactions.

Granularity can be specified in the minimum scale of time-outs such as 1, 10, 100 or 1000 milliseconds. If the granularity is better, it would improve the transaction response time as the waiting time for mobile users can be more frequently checked. In some cases, if the granularity approaches to the order of time-outs, the protocols would have to wait longer before time-out expires.

Fault-tolerance becomes important in supporting dependable transactions. As some group-oriented services could involve a single source (or coordinator) for use in multicast communications, the effect of source failure would be significant even if all the other users remain connected. In such cases, another user can be assigned to act as a back-up source.

If the information between different layers can be updated about the status of mobile users, then it could be possible for an application to specify a lower number of critical users thus increasing the probability of transaction completion. Such cross-layer communication would add some overhead and should be carefully measured.

A level of adaptability can be introduced in the protocols (UW, LW, SBW) to get optimal combination of response time and transaction completion for different applications under brief dis-connectivity or intermittent connectivity. The amount of additional overhead should be compared with any improvement in applications' performance.

The resource availability in wireless networks is likely to affect transaction response time. The effects of network congestion on protocol performance should be investigated. In this paper, we focus on user dis-connection due to mobility, obstacles, and links. The scenarios involving user's inability to participate in group-oriented mobile services due to network congestion or resource availability would be addressed in a future paper.

## 5. Performance Evaluation of Protocols

For our performance evaluation, the output parameters to measure are transaction completion probability and transaction response time under brief dis-connectivity and intermittent connectivity. The variable parameters are the number of users, the number of users needed to remain connected in a session, and, the frequency and duration of disconnectivity periods. A detailed performance evaluation process is shown in Figure 7.

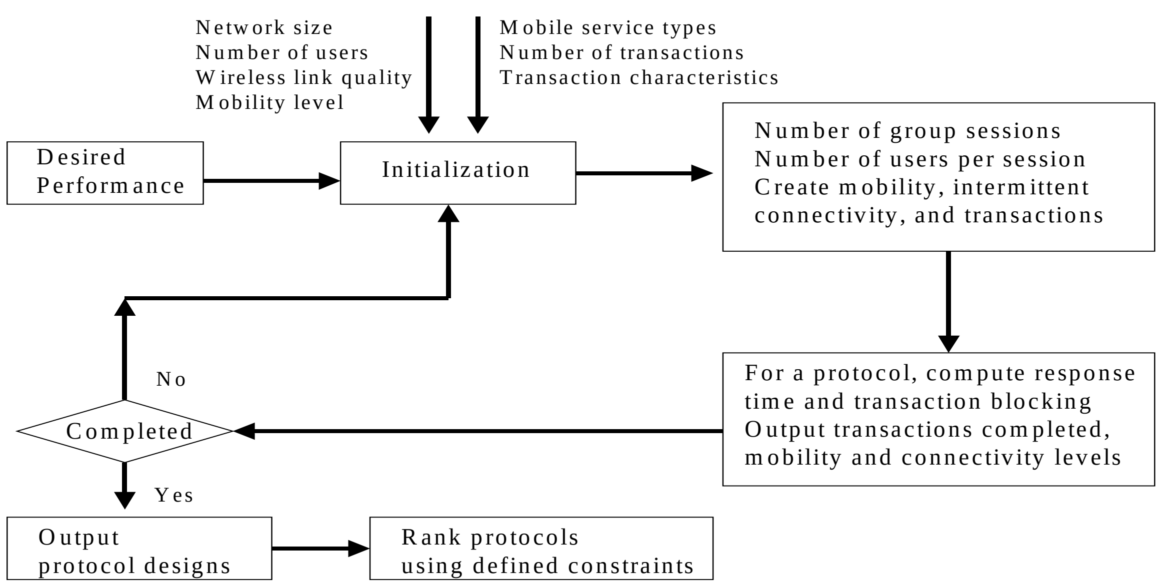


**Figure 7. Details of Performance Evaluation**

To compare the performance of three protocols, we have developed an analytical model. The model currently computes transaction completion probabilities for UW, LW, and SBW protocols under different number of users, connectivity and dis-connectivity durations, and number of users that must remain connected for a transaction to complete. The transaction response time can also be computed from the model for different protocols and connectivity conditions.

A transaction could be completed if M out of N users remain connected (for some transactions M has to be equal to N). The probability of transaction completion can be given as

$$P_T = \sum_{i>=M}^{N} {}^{N}C_i * (P_c)^i * (1- P_c)^{N-i} \quad \textbf{(1)}$$

where $P_c$ is the probability that a user remains connected

$P_c$ is given by

$$(D_{on}/(D_{on}+D_{off})) + (1/ N_{off}) \sum_{i=1}^{Noff} Prob(T_o >= D_{off-i})(D_{off}/(D_{on}+D_{off})) \quad \textbf{(2)}$$

where Don and Doff are the average time spent in the connected and disconnected stages, respectively. Non and Noff are the number of times users were in connected and disconnected states. Doff-i is the time spent in the ith disconnection and To is the time-out before a transaction is blocked. The value of To is dependent on the protocol used.

The active state of group can be given by

$$G = 1- (\sum_{i=1}^{Noff} min(To, Doff\text{-}i)/( \sum_{i=1}^{Noff} Doff\text{-}i + \sum_{j=1}^{Non} Don\text{-}j)) \quad \textbf{(3)}$$

The delay performance of protocols can be given by

$$Dt= (N/Ns)(D_{off}/(D_{on}+D_{off}))((1- P_c^{Ns})To + P_c^{Ns} To/2) \quad \textbf{(4)}$$

Where N is the total number of users in a transaction, Ns is the number of users in a stage, and Pc is the probability that a user is in connected stage when needed.

Using these equations, the performance of three proposed protocols is derived. The results are expressed in terms of transaction completion probabilities and average delay. The first set of results is shown in Figure 8 for dis-connectivity to connectivity ratio of 1:100 with average dis-connection lasting 1 second. The impact of Entities to Transaction Ratio (ETR) is significant for protocols 2 (LW) and 3 (SBW). For example, when using the timeout value of 0.5 seconds, the transaction completion probability drops from about 97% to 94% with the number of entities involved in a transaction increasing from 5 to 10. This reduction in completion probability occurred only when the additional entities were also mobile. For cases with fixed entities or entities with better connectivity patterns, the transaction performance remained about the same. We also found similar patterns when MMR was increased thus resulting in a higher number of members that experience connectivity problems.

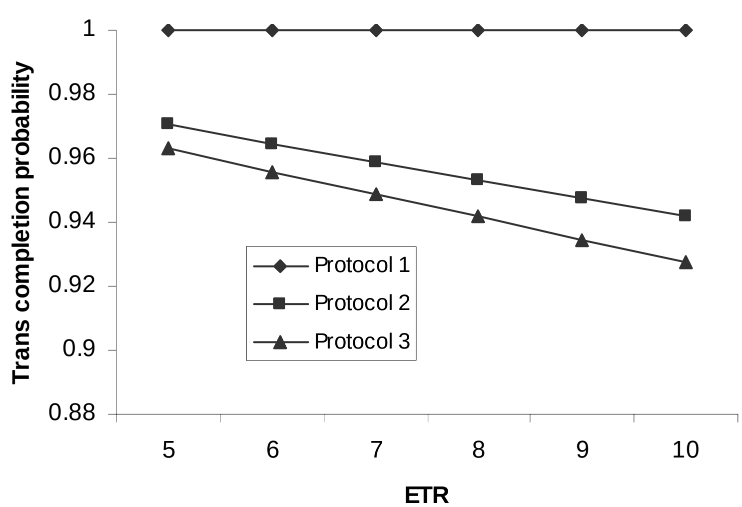


**Figure 8. The Impact of ETR on Transaction Completion Probability by Three Protocols**

Next we varied the connectivity and dis-connectivity patterns. It was assumed that all users eventually reconnect after a variable duration of disconnection. Figure 9 shows that connectivity and dis-connectivity pattern does not affect protocol 1 (UW) as it allows for an unlimited waiting time for all users. However, the negative impact is observed for protocol 2 (limited waiting=0.5 seconds) and 3 (status-based waiting of 0.5 and 0.1 seconds for the two classes of users), which perform better as the connectivity is improved. Also as the protocol 3 (SBW) reduces average waiting time further, it leads to a lower transaction completion probability. However, this results in a better transaction response time.

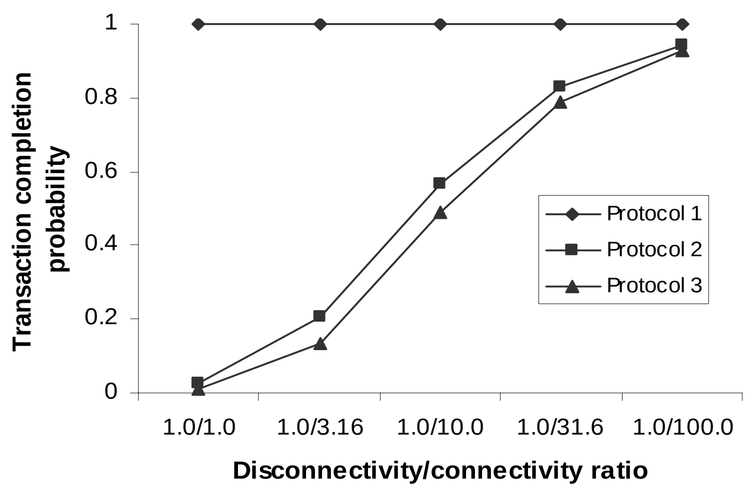


**Figure 9. Transaction completion probability under varying levels of connectivity**

The impact of minimum number of users that must remain connected for a transaction to get completed is shown in Figure 10. As the number is reduced, the performance is very high for all protocols. When very strict user connectivity is required by the application for completing a transaction, protocol 3 (SBW) performs poorly as it would timeout faster, thus leading to a reduced transaction completion probability. So it can be concluded that increased mobility can be compensated by an increased application flexibility up to a certain limit.

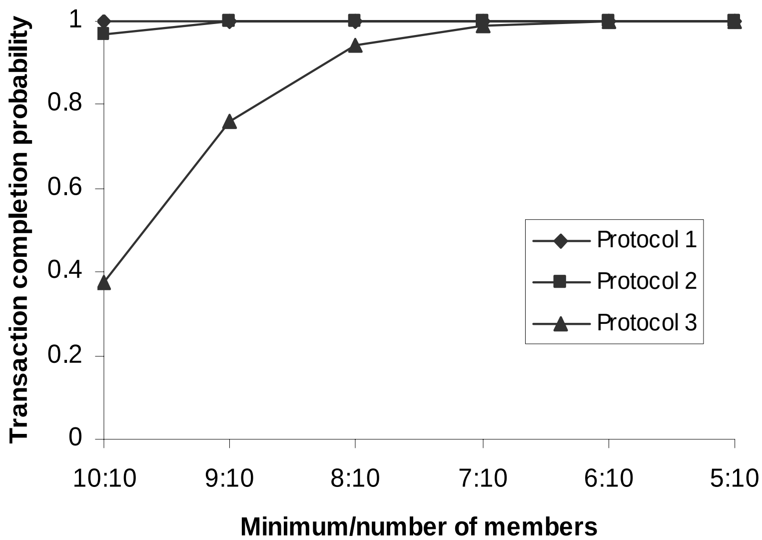


**Figure 10. Transaction completion probability under different application requirement**

Next we estimated the transaction delay produced by each one of the protocols. Although the maximum delay for protocol 1 (UW) can be unlimited due to its waiting pattern, we estimated the average delay for performance comparison. Also the total delay is dependent on the number of stages in an application, we derived that in most cases the total delay can be approximated as the product of average delay per stage and the number of stages in an application. We found that protocol 1 (UW) on average produces delays that may not be tolerable for many applications, while both protocols 2 and 3 generate delays that are much smaller thus capable of supporting more of real-time group-oriented mobile services (Figure 11). Please note that under fixed transaction length, a decreased TMP value in Figure 11 leads to lower delays for all the protocols (UW, LW, and SBW).

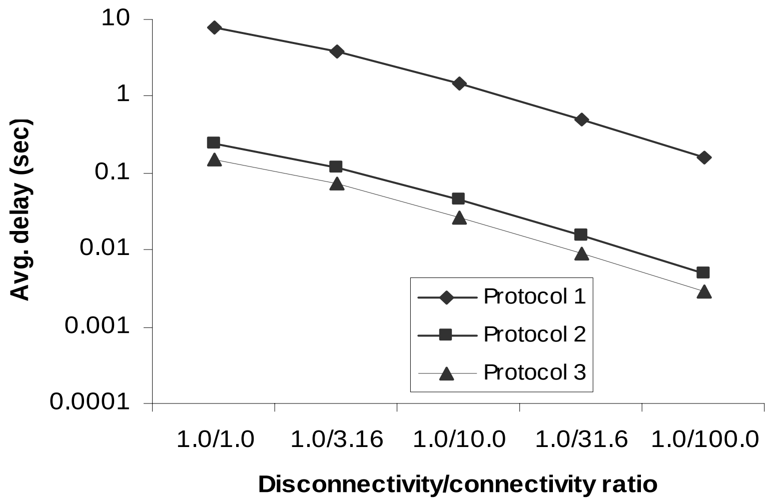


**Figure 11. Delays achieved by three protocols under varying levels of connectivity**

The major conclusions from our performance results can be summarized as follows:

1. The increased ratio of dis-connectivity to connectivity affects the performance of all three protocols. Although UW is designed to achieve very high transaction completion, it does come with an increased average and unbounded maximum delay.
2. UW can also provide reliable support for those transactions that are not delay sensitive. For delay sensitive transactions, either LW or SBW should be used.
3. The flexibility of group-application in the minimum number of required entities for transaction completion can be used to compensate the impact of increased or more frequent disconnections.
4. LW could be a good choice for many transactions requiring low delay and higher probability of transaction completion.

## 6. Conclusions and Future Scope

There has been very limited work in group-oriented mobile services under brief dis-connectivity and/or intermittent connectivity. To support such services, we derived the requirements of the emerging group-oriented mobile services, designed three multicast protocols to support diverse requirements, and, presented a detailed performance evaluation of three protocols under different connectivity conditions. One of the major requirements is a high completion probability for multicast transactions, especially when mobile users experience brief dis-connectivity and/or intermittent connectivity. These protocols allow the applications to handle such events gracefully. The results presented here showed that performance of these three protocols depends on the connectivity pattern and the application requirements. It is shown that high completion probability could be achieved by all three protocols under different conditions. It is also found that group applications with higher flexibility would be awarded with significantly higher transaction completion probability by all the three protocols. The flexibility of group-application in the minimum number of required entities for transaction completion can also be used to compensate the impact of increased or more frequent disconnections. The increased ratio of dis-connectivity to connectivity is shown to affect the performance of all three protocols. Protocol 1 (UW) can provide reliable support for those transactions that are not delay sensitive. For delay sensitive transactions, either protocol 2 or 3 can be used, especially protocol 2 (LW) could be a good choice for many transactions requiring low delay and higher probability of transaction completion.  The further research in this area could include how to achieve an optimal combination of response time and transaction completion probability for different mobile services.

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