Mobile Networks and Applications 7, 225–234, 2002

Supporting Mobile Commerce Applications Using Dependable Wireless Networks

ALISHA D. MALLOY, UPKAR VARSHNEY and ANDREW P. SNOW
Department of Computer Information Systems, Georgia State University, Atlanta, GA 30302-4015, USA

Abstract. Mobile commerce (m-commerce) is an emerging discipline involving applications, mobile devices, middleware, and wireless networks. While most of existing e-commerce applications can be modified to run in a wireless environment, m-commerce also involves many more new applications that become possible only due to the wireless infrastructure. These applications include mobile financial services, user and location specific mobile advertising, mobile inventory management, wireless business re-engineering, and mobile interactive games. In addition to device and wireless constraints, mobile commerce would also be impacted by the dependability of wireless infrastructure. Unlike e-commerce applications that usually run on fixed networking infrastructure of fairly high dependability (approaching to about 100%), m-commerce applications may not receive such high dependability from the existing and emerging wireless infrastructure. So far, most of the m-commerce research focuses on applications, devices, and security issues. We believe that some work is necessary in addressing the dependability challenges of the wireless infrastructure. In this paper, we present (a) the dependability issues of wireless infrastructure, (b) several architectures to improve the dependability of wireless networks, and (c) a simulation model and results on wireless dependability for m-commerce. The results show that a significant improvement is possible in wireless dependability for supporting m-commerce applications.

Keywords: e-commerce, m-commerce, wireless networks, dependability, reliability, availability, survivability, simulation, performance evaluation

1. Introduction

Electronic commerce has attracted significant attention in the last few years. This high profile attention has resulted in significant progress towards strategies, requirements, and development of e-commerce applications. M-commerce is an emerging discipline involving applications, mobile devices, middleware, and wireless networks. While most of existing e-commerce applications can be modified to run in wireless environment, m-commerce also involves many more new applications that become possible only due to the wireless infrastructure [8]. Unlike e-commerce applications that usually run on fixed networking infrastructure of fairly high dependability (approaching to about 100%), m-commerce applications may not receive such high dependability from the existing and emerging wireless infrastructure. So far, most of m-commerce research focuses on applications, devices, and security issues. We believe that some work is necessary in addressing the dependability challenge of wireless infrastructure. Dependability can broadly be characterized by reliability, availability, and survivability of wireless networks. Though somewhat interrelated, the terms reliability, availability, and survivability have different meanings. In our context, reliability is the ability of wireless and mobile networks to perform their designated set of functions under certain conditions for certain operational times [2]. Network availability can be expressed in terms of the fraction of time users are able to access network services. The term survivability refers to a wireless network's ability to perform its intended services, given network infrastructure component failures.

The mobile commerce applications include mobile financial applications, mobile advertising, mobile inventory management, product locating and shopping, wireless re-engineering, mobile auction, and wireless data center [8]. These applications have diverse networking requirements in terms of location management, QoS, and dependability. The impact of lack of wireless dependability is likely to be quite different for these applications. For example, applications such as mobile financial applications may be more affected by failures in wireless networks than applications such as mobile advertising where value and real-time processing may not be crucial factors. Applications that will be affected by wireless dependability include

- applications requiring real-time or immediate wireless service (such as mobile financial applications, mobile inventory management, wireless re-engineering, auctions, and data center);
- applications that may involve multiple devices, databases, and other network components to complete a transaction (such as auctions and mobile inventory management);
- applications requiring authentication and authorization from one or more servers and devices (mobile financial applications, wireless re-engineering).

Now we look into a generic m-commerce transaction and discuss how different m-commerce transactions may be affected by different failures in wireless infrastructure. Such a model is shown in figure 1. A mobile commerce transaction may involve multiple network components such as location database, user preference database, and multicast server.

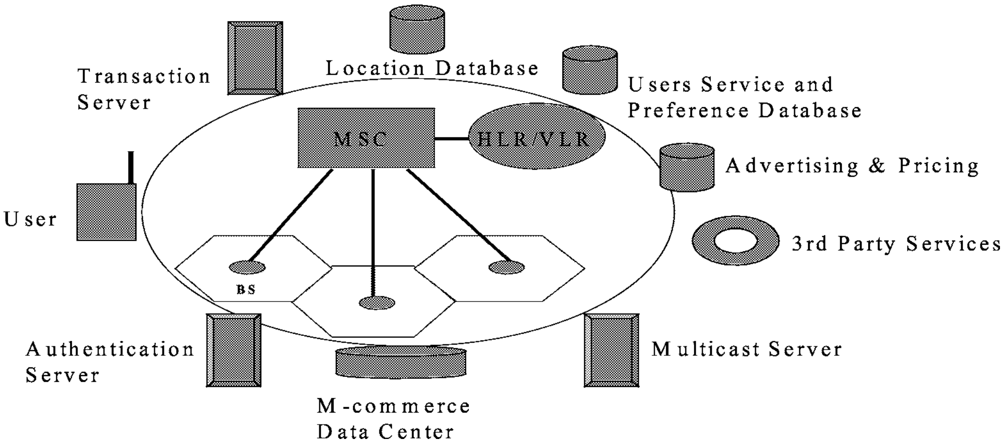


Figure 1. Possible components in a m-commerce transaction.

Table 1
Impact of wireless infrastructure failures on m-commerce applications.

Type of failures	M-commerce applications affected
Device/Server/BS/MSC/ Transaction Server	All
HLR/VLR or Location Database	Mobile financial applications (B2C, B2B) Mobile advertising (B2C) Mobile inventory management (B2C, B2B)/ Product locating and shopping (B2C, B2B) Proactive service management (B2C, B2B) Mobile auction or reverse auction (B2C, B2B)
Multicast Server	Mobile auction or reverse auction (B2C, B2B) Mobile advertising (B2C) Mobile distance education (B2C)
User Preference Database	Mobile advertising (B2C)
Authentication Server	Mobile financial applications (B2C, B2B) Mobile auction or reverse auction (B2C, B2B) Wireless re-engineering (B2C, B2B)
Data Warehouse	Wireless Data Center (B2C, B2B)

Note: B2C: business-to-consumer, B2B: business-to-business.

Also different transactions may require very different types and number of network components (table 1). For example, mobile auctions may need multicast, location, and authentication servers, while mobile advertising could just use a location database. Therefore, failures of different network components would affect mobile commerce transactions differently. Also some failures such as device failure, switch failure, or server failure may affect most or all of the applications, while other failures such as multicast server failure may only affect applications requiring multicast. Even there, broadcast limited to some locations may be performed to support such applications, although at much more inefficient use of the wireless infrastructure. Also the impact of failures may also depend on whether the mobile commerce transaction used a "Push" or "Pull" format. In the first case, a user may not even notice the impact of a failure, while in second case the user will notice the delay/time-out or the lack of service after the user has attempted a transaction.

The dependability of the wireless infrastructure is a very crucial requirement for supporting m-commerce applications. The dependability of wireless networks for existing applications (voice/data) is an important issue [6], however this becomes even more crucial for m-commerce due to the following reasons:

- Unlike existing wireless applications, m-commerce transactions are likely to use several network components simultaneously including one or more databases (especially for applications requiring network wide multicast communications), making the impact of one failure to be felt at several other places.
- M-commerce applications are likely to use computing and communications resources more often than regular applications, making the effect of component/link failures even higher.
- M-commerce applications are likely to involve much more valuable transactions, making the financial impact of failures and unavailability much higher.
- M-commerce applications are likely to involve several different wireless networks, devices, and software, and weakness in one or more such components is likely to affect the overall dependability.

We now turn to our approach for improving and providing application specific wireless dependability in section 2. In section 3, we present a simulation model and results to show the improvements in wireless dependability by both design changes and fault-tolerant architectures. In section 4, we briefly discuss some related work. Finally, in section 5, we make some concluding remarks.

2. Improving wireless dependability for m-commerce

In this section, we address how to increase the dependability of wireless networks for m-commerce applications. Dependability can be characterized by reliability, availability, and survivability of wireless networks. Though somewhat interrelated, the terms reliability, availability, and survivability have different meanings. In our context, reliability is the ability of wireless and mobile networks to perform their designated set of functions under certain conditions for certain operational times [2]. The most common reliability metric is mean-time-between-failure (MTBF). Availability refers to a network's ability to perform its functions at any given instant of time under certain conditions [2]. Network availability can be expressed in terms of the fraction of time users are able to access network services. The term survivability refers to a wireless network's ability to perform its intended services, given network infrastructure component failures.

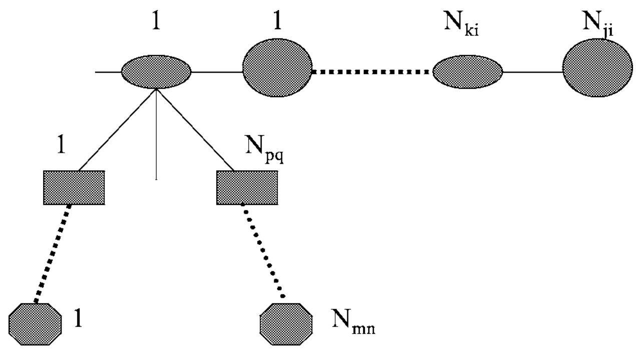
By increasing the MTBFs of different components/links and by some architectural changes (such as redundancy or fault tolerance), reliability of wireless and mobile networks can be improved. We propose an integrated approach for improving overall dependability of wireless infrastructure to the application specific requirement. We next discuss how the dependability of wireless networks can be improved using design changes. Following that, we will discuss fault-tolerant architectures.

2.1. Improving dependability using better design and components

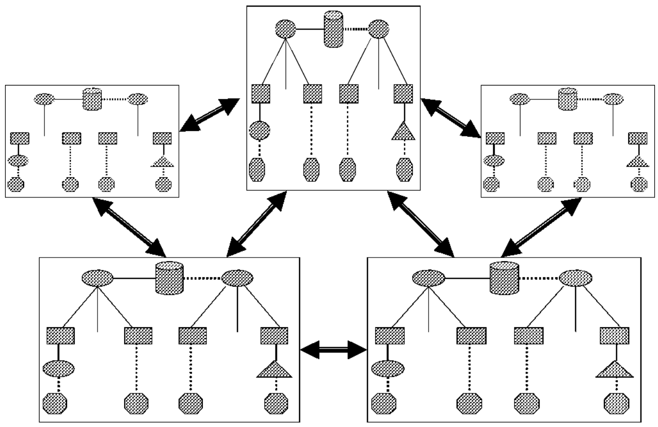
The dependability attributes of wireless networks may be enhanced by certain design changes. This could include the deployment of more reliable components and links and also how these components are interconnected. The dependability can further be improved by establishing a faster recovery time. To address how better design impacts dependability, we used a building block approach. This approach is based on using wireless infrastructure building-block (WIB) that contains a Mobile Switching Center (MSC) and associated Home/Visitor Location Registers (HLR/VLR), multiple base station controllers (BSCs), and several base stations (BSs) homed to a base station controller [7].

In general terms, wireless dependability can be improved with increased MTBF (mean-time-between-failure) of components and reduced MTR (mean-time-to-restore). The increased MTBFs would reduce the frequency of failures, thus reducing the number of transactions that are impacted by wireless failures. Reduced MTR would reduce the duration when mobile commerce transactions could not access the wireless infrastructure. We also believe that varying the size of infrastructure block, the number of levels in a block, the number of components/links, and the size of components/links may have positive impact on one or more of dependability attributes (reliability, availability, and survivability). Increased availability of wireless infrastructure would reduce busy signals/blocking allowing more users to complete their transactions at anytime. The increased survivability would reduce the number of transactions impacted after one or more failures have occurred in the underlying wireless infrastructure.

A generalized WIB is shown in figure 2(a) that includes multiple levels. Further, each level may include multiple components of different types. Even among the components



(a)



(b)

Figure 2. (a) A generalized wireless infrastructure-building block (WIB). N_{ij} is the number of components of type i at level j of a WIB. (b) A wireless network designed with several different WIBs.

of the same type, the characteristics may differ. For example, a base station may significantly differ from a neighboring one in terms of number of customers supported, MTBF and MTR values, and hardware/software functionalities.

Using WIB approach, a wireless network may include multiple WIBs of varying sizes. The following parameters can be selected to optimize one or more of the dependability attributes:

- size and number of building blocks,
- the number of levels in a building block,
- the number of different types of components,
- the number of components of a certain type in a given level,
- the size of different components in terms of number of customers supported,
- characteristics of components (MTBF, MTR).

We believe that above factors would lead to improved support for a range of mobile commerce applications in terms of the number of completed transactions.

Figure 2(b) shows a network made up of multiple building blocks of different sizes, levels, and components and links. One or more of these can be selected to optimize one or more dependability attributes. Also these parameters can be varied to provide the required levels of dependability attributes in different locations covered by a wireless network. For example, the dependability attributes required in areas of significant business activities may differ from those required in rural areas. Such location-specific dependability research will be addressed in a subsequent paper.

In the next section, we present some interesting results showing how much improvement is possible in each one of these attributes under what conditions. We believe these results are of significant importance to the required wireless dependability for m-commerce applications.

2.2. Improving dependability using fault-tolerant architectures

Fault tolerance can be introduced in wireless networks in one or more places. These include device, cell, switch, block, and network levels. This leads to several possible fault-tolerant architectures for m-commerce. Fault tolerance at device level can be introduced in the device where multiple interfaces can be incorporated in a device. These interfaces can be used to access the same network, thus, one is primary and others are backup interfaces as shown in figure 3(a). Such an architecture would reduce the impact of failures on most m-commerce transactions.

Fault tolerance at the cell level can be introduced by using multiple base stations per cell or overlapping (hierarchical cell structure) cell structure. The use of multiple base stations to cover one cell may be expensive as only one of the base stations is used at any time. The number of base stations per cell in such a scheme may also be determined by the MTBF ratings of these base stations and the level of network availability desired. A possible scenario is shown in figure 3(b). Such an architecture would support most m-commerce transactions but higher transaction/blocking may result due to a reduction in wireless resources after failures.

Fault tolerance at the switch level can be introduced by redundancy or by using a fault-tolerant architecture such as SONET ring as shown in figure 3(b). Also a base station may be connected to more than one switch (multi-homing) to overcome failure of one or more switches. Fault tolerance at block level can be introduced as follows. Since multiple such blocks may need to be interconnected to cover the entire service area, interconnection issues arise. The type of information that has to be transmitted between these blocks includes user traffic

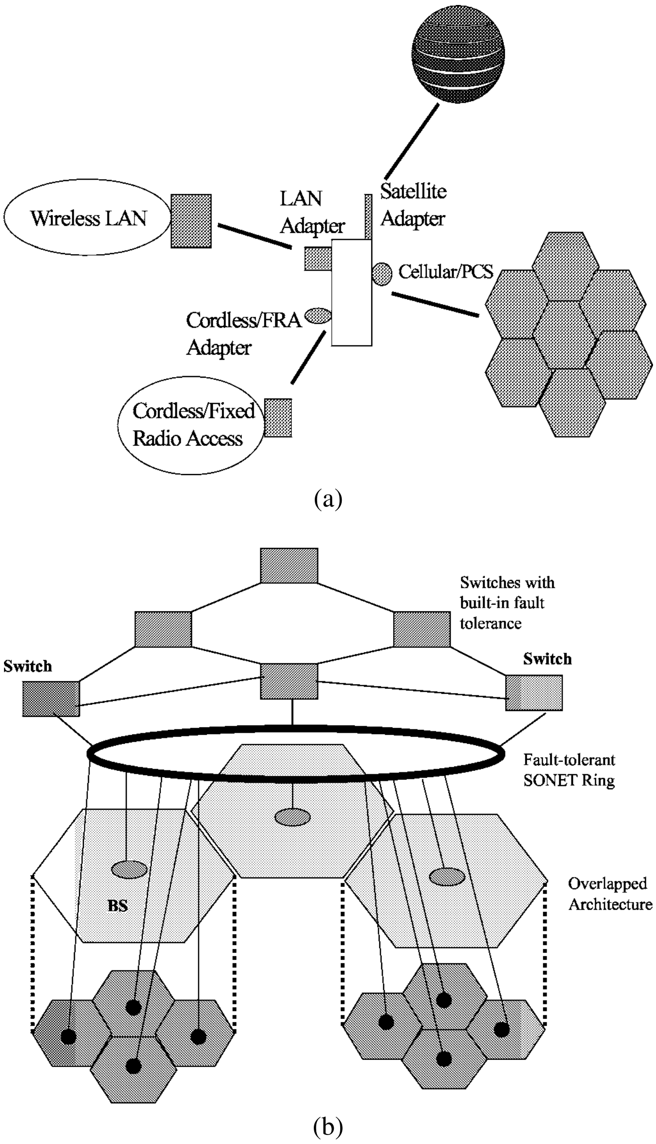


Figure 3. (a) Fault tolerance at the device level. (b) Fault tolerance at cell and switch levels.

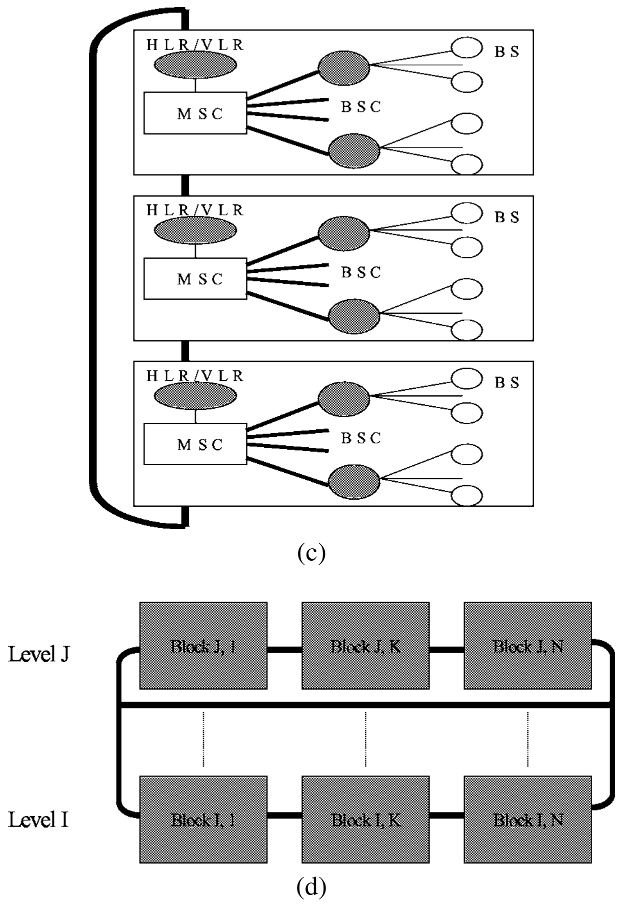


Figure 3. (c) Fault tolerance at the block level. (d) Fault tolerance at the network level.

to and from a given block and signaling, and control traffic. A failure of one or more links connecting these blocks together may partly or fully disable the operation of a building block affecting a number of customers. So a fault-tolerant architecture such as SONET ring can be used in interconnecting these blocks as shown in figure 3(c). If a cut in the ring occurs, the rings join and the network connectivity is maintained. If an MSC fails in a block, then only that block is isolated, but the other blocks remain connected to one another. Such architecture would support mobile commerce applications that require reliable inter-WIB connectivity.

Fault tolerance at the network level can be introduced to increase the availability by using network replicated at the block level. Thus, there are two or more blocks covering a certain area. These layers and the interconnection architecture at intra and inter layer levels may provide a degree of fault tolerance as shown in figure 3(d). Such architecture would allow the support for m-commerce applications even after one or more blocks are completely disabled.

After discussing the use of different architectures to improve the dependability of wireless networks for m-commerce applications, we next discuss how to simulate the performance improvements by one or more of these architectures. A comparison of these fault-tolerant architectures is not included here due to space limitation. A future paper will include such comparison for both existing as well as the emerging m-commerce applications.

3. Modeling and performance evaluation

To study wireless dependability for m-commerce applications, we developed a discrete event simulation model using the building block approach. The number and size of building blocks are determined based on the total number of subscribers served. Then the number of levels and the number and size of different components in a building block are set. Although the impact of network failures is likely to affect various mobile commerce applications differently, we are interested in evaluating the number of transactions impacted by a range of wireless infrastructure failures. We will also evaluate the improvement in number of transactions completed due to improved wireless infrastructure. We are aware of the fact that the sheer number of transactions may not represent the overall impact on m-commerce applications as the impact is dependent on the distribution and the exact mix of m-commerce applications in use at the time of various failures. Since we do not deal with such mix of diverse m-commerce applications in this paper, we chose to focus on the number of transactions that are affected by the dependability of wireless infrastructure.

The simulation model designed and used in this study produce failure statistics and total impact of failures on m-commerce transactions. We will use the model to compute failures and impact under varying network size, duration, component characteristics, and other variables. A step-by-step description of the algorithm used in the simulation model is presented in table 2.

We used the following values for a building block (or WIB: wireless infrastructure block) as suggested in [7]:

- Number of MSC/HLR/VLR in a block = 1.
- Number of BSCs under an MSC = 5.
- Number of BSs under a BSC = 10.
- Number of users served by a base station = 2000.
- Number of users served by a BSC = 20,000.
- Number of users served by a building block = 100,000.
- Mean number of transactions per user = 1, 5, or 10.

Next, we analytically model the number of component failures, the quantitative impact of various failures, and network availability. We derived this model to capture the number of component failures, the quantitative impact of various failures, and network availability. The impact of component failures is shown in the fault tree of figure 4. A level 1 failure involving MSC, HLR/VLR, SS7, and PSTN trunk affects the entire user population of a wireless building block. A level 2 failure involving BSC affects all BSs and their associated users. A level 3 failure only affects users under the coverage of a single base station.

The probability of R failures for the components/links of type k in the sample period can be approximated as

$$P_{k\text{-total}} = {}^{N_k}C_R \cdot (P_{ki})^R \cdot (1 - P_{ki})^{N_{k-R}},\\ \text{where } P_{ki} = 1 - \mathrm{e}^{-d\lambda_{ki}}, \tag{1}$$

- k = specific component type in the network,
- d = time period,
- λ_{ki} = failure rate of the ith component of the type k and is a function of MTBF and can be approximated as the inverse of MTBF,
- N_k = number of components of type k in the network,
- R = number of failures.

The total number of failures involving components and links of type k in a WIB during a given time can be approximated by

$$N_{k\text{-total}} = \sum_{R=1}^{N_k} R \cdot \left({}^{N_k}C_R \cdot (P_k)^R \cdot (1 - P_k)^{N_{k-R}}\right). \tag{2}$$

The total number of failures in a network of M WIBs during a time period can be given as

$$N = \sum_{i=1}^{M} \left(\sum_{k=1}^{C_{\max}} N_{k\text{-total}} \right), \tag{3}$$

- $C_{\max}$ = total number of different components and links in a WIB,
- M = number of WIBs in the network.

The cumulative impact of failure (number of transactions affected) in a WIB with N levels can be given by

$$I_{\text{WIB}} = TR_{\text{avg}} \cdot \sum_{i=1}^{S} \left[\prod_{k=1}^{i-1} (1 - P_k) \right] \cdot \sum_{k=1}^{T_i} P_{ik} I_{ik}, \tag{4}$$

Table 2
A step-by-step description of simulation model.

Actions	Comments
Step 1 Get number of users (or network size). Get/generate mean and distribution of transactions/user, user mobility levels, building block architecture (levels) and distribution, characteristics of components and links, and failure thresholds.	1. Information on the type of wireless network is either entered by a user or is initialized by the simulation model. 2. Characteristics of components may include minimum/maximum size, MTBF and MTR, and a function describing the relationship between these two.
Step 2 Generate the number and sizes of building blocks using a given distribution. Generate levels, components, and links based on information from step 1, or Initialize to a starting value. Generate different transactions for users. Schedule failure events using user-specified or model-selected distribution and mean values.	The internal architecture for different building blocks is generated based on the input or using built-in values in the model.
Step 3 Check for failure events throughout the network. If failure occurs, execute failure processing (step 4). Else move simulation clock to the next failure event.	
Step 4 Failure processing Add to Num_Failures. Check and process overlapping failures. Identify the level where failure has occurred and ignore downstream failures under the same sub-tree in the same building block. Derive failure size and duration using given distributions (such as exponential, Weibull). Check if failure size exceeds one or more thresholds. Add failure size to Num_User_Impacted. Compute the number of transactions for users affected by failures. Add to Num_Transaction_Impacted. Add durationXsize to Net_Down_Factor. Generate repair time using input information or model values and given distributions (Weibull, exponential, or binary). Go to step 3.	
Output the following values:	
Num_Failures	Num_Failures is a reliability metric.
Num_User_Impacted Num_Transaction_Impacted	Num_User_Impacted and Num_Transaction_Impacted are survivability metrics.
Net_Down_Factor	Net_Down_Factor is an availability metric.
Num_Threshold	Num_Threshold represents the number of failures exceeding certain time or impact thresholds.

- S = number of levels in a WIB,
- P_{ik} = overall probability of failure of the kth component at level i,
- I_{ik} = impact of component or link based on the size of the network,
- T_i = total number of components or links at level i,
- TR_{avg} = average number of transactions per user = $\sum(i Q_i)$, where Q_i represents the probability of i transactions.

The network availability under failures can be given by

$$A_{\text{WIB}} = 1 - \sum_{k=1}^{N} \frac{\sum_{i=1}^{N_k} D_{ki} I_{ki}}{Wd}, \tag{5}$$

- N = total number of failures in the network,
- D_{ki} = MTR of the ith component of type k,
- I_{ki} = number of subscribers impacted by the ith component of type k,
- W = total number of subscribers in the WIB,
- d = test duration.

Using equations (1)–(3), we verified the reliability results obtained from the simulation model. We used equation (4) for survivability and (5) for availability results.

We used low-nominal-high values for MTBF to derive our results. These values are shown in table 3 [7].

Using the above values, we obtained simulation results for the number of users impacted by different network failures. For this investigation, we present the number of users impacted a day for network infrastructures ranging from 100,000 to 10,000,000 users for the low, nominal, and high MTBF cases. These results are shown in figure 5. Note that for the nominal case, failures in a 1,000,000 wireless infrastructure (10 WIB) can expect to impact about 5,000 users

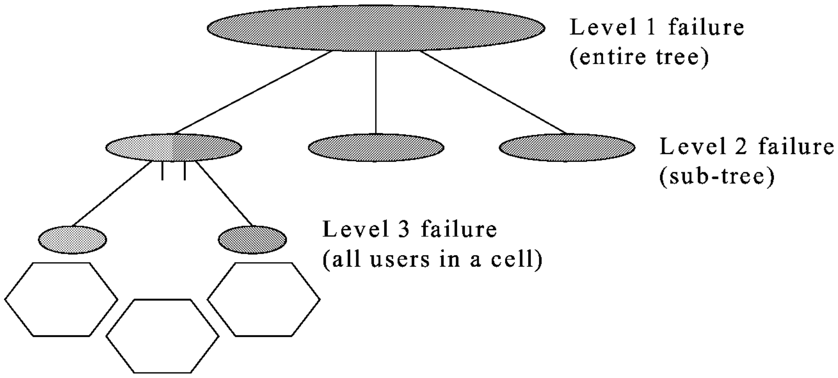


Figure 4. Impact of different levels of failure in a WIB.

Table 3
Low-nominal-high MTBF values (years).

Component/link	Low	Nominal	High
MSC	5	7.5	10
DB	2	3	4
MSC-BSC	3	4	5
BSC	3	4	5
BSC-BS	1	3	5
BS	1	2	3

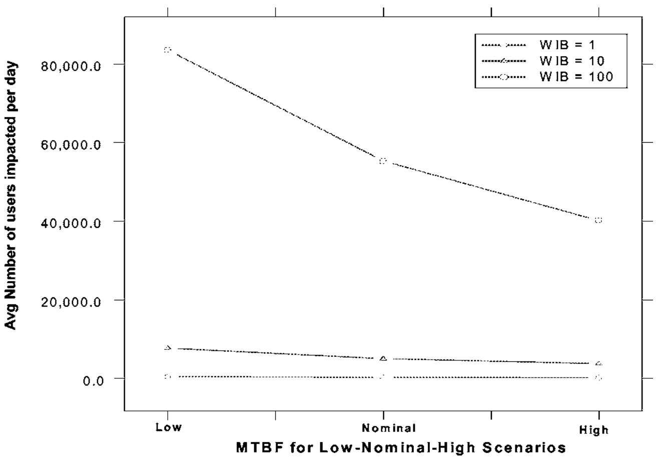


Figure 5. Measuring the impact of failures under nominal reliability of components.

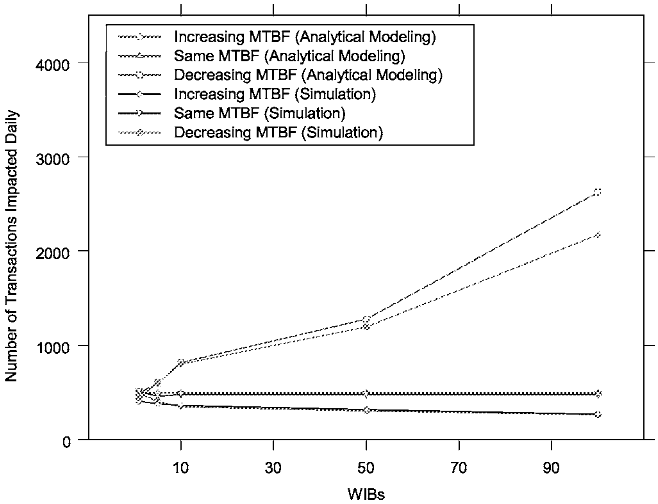


Figure 6. Measuring the impact of component sizes and reliability.

a day, or about 0.5% of the users. The impact may even be worse if the reliability of components and links is actually lower than what is assumed here in the simulation. Also in case of dependent failures, where failure of one component/link may trigger failures of other components, the impact may even be higher. The actual number of m-commerce transactions that are affected by different failures in wireless infrastructure can be computed by deriving the transactions that a user was executing at the time of failure and the number of transactions the user may have executed during the failure duration.

Next we attempt to measure the impact of failures on m-commerce transaction under variable size of building blocks. There are two possible ways to vary the building block size. The first is by keeping the same number of components and links but varying their sizes and the second is to keep the same size but vary the number of components and links in the same proportion. For simulation purposes, we used the first approach where we varied the size of components in the same proportion as the size of building block. So if its size were reduced to half, we would use components and links that are covering half as many users. One important point that should be noted here is that the reliability of components or links may change with size. For simulation purposes, we have considered all the three possibilities: increased, same, and reduced reliability with increased size. It is possible that vendors may add special features for improving reliability of larger components. On the other extreme, it is also possible that increased size may simply lead to a higher failure rate. To estimate the impact of component size and corresponding change in reliability levels, we assumed the same number of customers (100,000 total customers). For cases of increased reliability with size, the MTBF was increased by 20% for every change in component size. For cases of reduced reliability, the MTBF was decreased by 20%. The simulation as well as analytical results, including the number of transactions impacted, are shown in figure 6 (I, S, and D represents the increasing, same, and decreasing reliability levels). One interesting result here is that there is

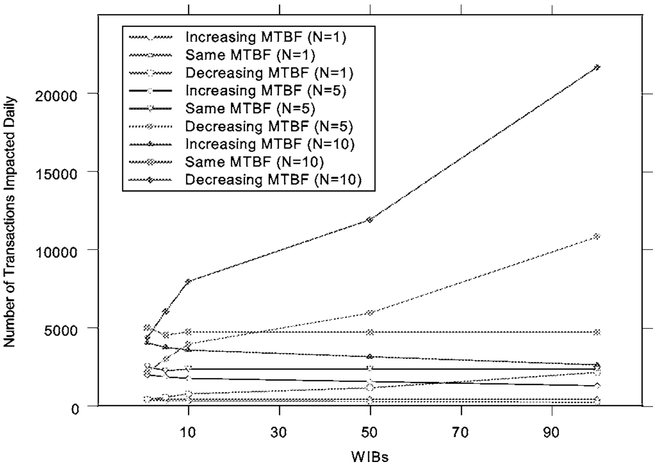


Figure 7. Failure impact of network size under multiple transactions per user.

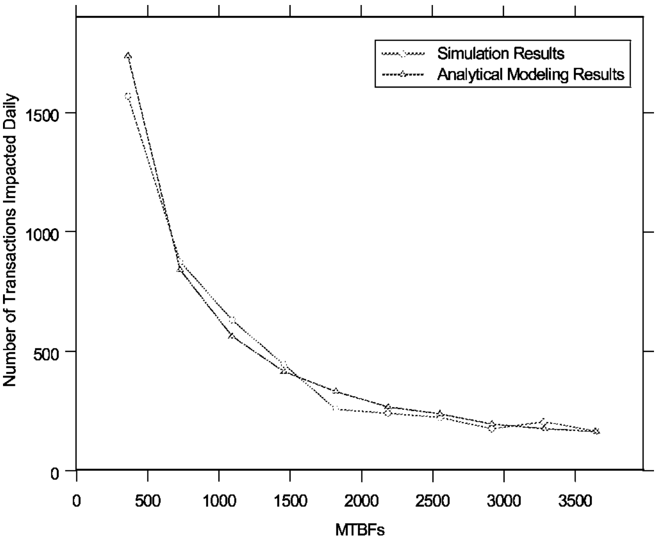


Figure 8. Impact of MTBFs on m-commerce transactions.

not much improvement possible in the network survivability just by increasing the reliability of components when the size becomes smaller. However, if the reliability level drops as the size becomes smaller, then the number of transactions affected would increase significantly. In one of the results from figure 6, more than 2000 transactions (out of 100,000) may be affected daily, if smaller components with lower reliability levels are used.

Next we investigated the number of transactions that may be affected in a day under variable number of transactions for different users. These results show that decreased component and link qualities in a larger network may lead to a significant effect on mobile commerce transactions as shown in figure 7. It can also be observed that beyond a certain level of component and link reliability, not much survivability improvement is possible for m-commerce transactions.

The impact of reliability levels on m-commerce transactions is shown in figure 8, where the number of transactions impacted daily are shown using both simulation as well as analytical modeling techniques. It shows that at about MTBFs

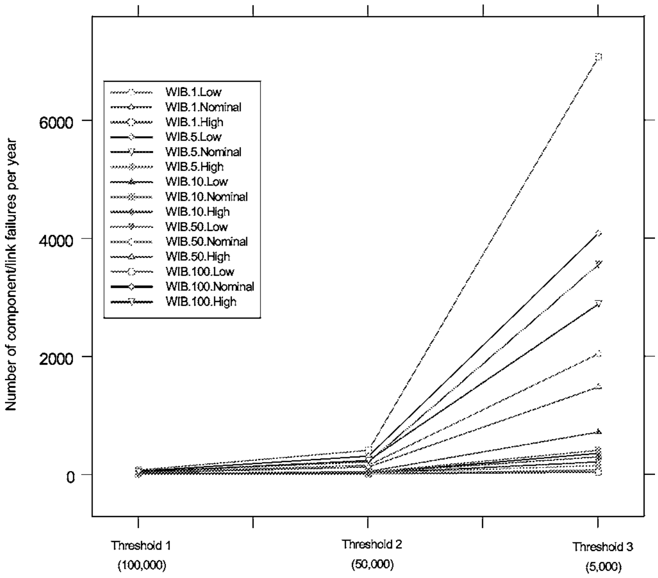


Figure 9. Measuring the number of failures exceeding different thresholds.

of 6 years (2000+ days), asymptotic improvement is reached for m-commerce transactions.

Besides knowing the total number of transactions that are affected by various infrastructure failures, it may be important to know how many of these failures actually affect more than a certain number of transactions in a day. Such information may be of importance to wireless carriers and operators for network management or reporting purposes. Such data could also be used by service providers for pricing and service negotiations with m-commerce customers. Knowing how many such failures occur and where in the network, network designers could make design improvements to minimize the occurrences of these high-impact failures. In our simulation, we used three different thresholds: 100,000 (large-scale failures), 20,000 (medium-scale failures) and 5000 (small-scale failures). These are named threshold 1, 2, and 3 for discussion purposes. The simulation results for varying network size and reliability (MTBFs from table 3) are presented in figure 9, where numbers of failures that exceed three different thresholds under varying degree of reliability are shown. Using these results, a suitable threshold may be chosen for failure reporting for network management. These numbers provide different insights into the impacts caused by failures and can also be used as reporting thresholds to vendors, users, and other providers.

The results presented so far include the effects of failures under varying parameters (time, size, number, reliability, and thresholds) on the m-commerce transactions of users in one or more building blocks. Now we turn our attention to reducing the number of transactions impacted by using fault-tolerant architectures. To evaluate any such improvements, we have considered three different architectures for interconnecting seven different WIBs. These are single ring, star, and dual ring. For the three interconnection architectures, the impact of failures under different reliability and mobility levels is shown in figure 10. To evaluate the performance of differ-

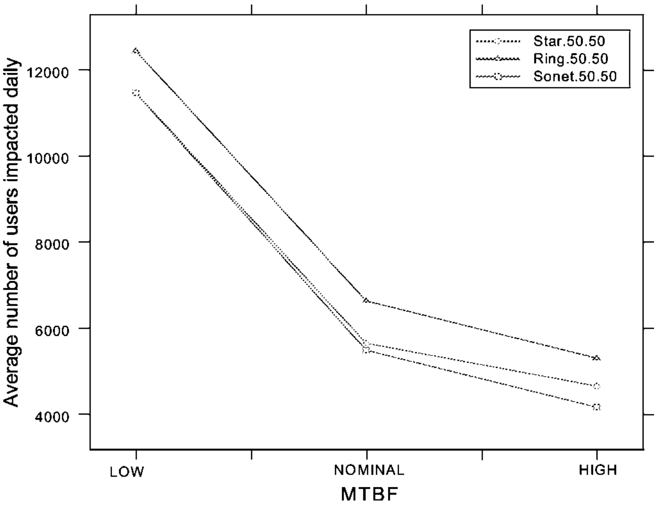


Figure 10. Fault tolerance and improvements in wireless survivability.

ent architectures, we have assumed an interconnected 7-WIB cluster where each WIB serves 100,000 customers. Simulation results were obtained for varying levels of mobility involving different compositions of users in a WIB. The results shown in figure 10 correspond to a scenario where 50% of users registered in a building block are visiting other places. The results indicate that a network with basic dual-ring structure outperforms the networks with Ring and Star interconnecting architectures. One point that should be noticed here is that the results show the overall survivability of a wireless network does not just depend on the interconnecting architecture (ring, star or dual ring) used. What is interesting to observe is that at the low MTBFs, both networks with dual ring and star perform about the same; only at higher MTBFs can a difference be seen between the two networks. This can be explained as follows. When the components/links are more reliable, then the reliability of interconnecting architecture has more impact on the overall network survivability level. When the individual components/links in a building block are more prone to failures, then the impact of failure of the interconnecting architecture would have a smaller share on the overall impact. The only exception may be a ring, where a single cut in the ring may disable the entire network. So it can be concluded that a reduction in number of transactions impacted by failures can be achieved using fault-tolerant architectures when the individual building blocks show a nominal to high level of internal reliability. These observations would have an influence on cost/benefit analysis when the MTBFs of the components/links were low. Similar results were obtained for other levels of mobility.

From the simulation results, we conclude that a significant improvement in wireless dependability can be achieved for m-commerce with increasing MTBF of different components and links. We also found that the in some cases, dependability for m-commerce can be improved using fault-tolerant architectures. We also found that fault-tolerant architectures may not be very useful when reliability levels of individual components and links are poor. Several other results were also obtained that supported the same conclusions. We believe that more work is needed in comparing the improvements made in each of the dependability attributes by the proposed architectures for m-commerce. For implementation purposes, it may be important to find out which combinations of these architectures and design changes produce the most improvements in wireless dependability for m-commerce applications. Our future work will address these issues.

4. Related work

Although dependability of wireline networks has been studied and researched in the last few years, very little work has been done in applying that to wireless and mobile networks, and none so far for m-commerce. We have performed a near-exhaustive literature search and have found very little published research on wireless reliability, availability, and survivability issues. Here we include a brief discussion of related published research in this area.

A study of restoring mobility databases, HLR/VLR, after a failure, was presented in [3]. The database restoration was proposed using checkpointing with optimal intervals to balance the checkpointing cost against the paging cost. A subsequent study investigated the location update costs in the presence of database failures [1]. The use of two-tiered PCS systems to increase user availability under network failure was conducted in [4]. Three different architectures to increase the fault-tolerance of wireless networks were presented in [6]. The proposed architectures included the use of SONET rings and use of overlapping base stations, access to multiple wireless networks to increase user-perceived network availability, and use of overlay networks connecting universal access points (UAPs). A study on the affect of failures on users, not initially impacted by a failed component, was presented in [5]. It computed the impact of a failed base station on the registration and other delays as seen by users in neighboring cells. Recently a simulation-based framework was proposed for studying the reliability, availability, and survivability of wireless networks [7].

5. Conclusions and future research

M-commerce is an emerging discipline involving mobile devices, wireless networks, applications, and middleware. Due to the increased integration of several applications, protocols and infrastructure necessary to perform effective and efficient business processing, m-commerce provides unique challenges to the existing wireless infrastructure. As these applications are being designed, one important issue is the specific infrastructure requirements and how existing and emerging wireless networks can meet these. In this paper, we presented various infrastructure requirements of the emerging m-commerce applications. In particular, we discussed the dependability of wireless infrastructure for m-commerce applications. We have presented several architectures and design changes to improve the dependability of wireless infrastructure for m-commerce. To evaluate the effectiveness of our proposed design and architectural changes, we developed and used a simulation model. The simulation results included in the paper showed improvements in dependability attributes using both the improved network design and fault-tolerant architectures. We believe that more work is needed towards improving the wireless infrastructure for supporting m-commerce applications. It is our hope that our work may form a basis for further research in wireless dependability for m-commerce.

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Alisha Malloy is currently a Ph.D. candidate and KPMG Scholar at the Department of Computer Information Systems at Georgia State University. She received MS in engineering management from Old Dominion University and BS in general engineering from the US Naval Academy. She has written several papers on wireless dependability, quality of service, and mobile commerce with her Ph.D. advisor, Upkar Varshney. She is expected to graduate during summer 2002 and will join University of Alabama as an Assistant Professor of Information Systems.
E-mail: amalloy@gsu.edu

Upkar Varshney is an Assistant Professor in the Department of Computer Information Systems at Georgia State University, Atlanta. He received a Bachelor of Engineering in electrical engineering with Honors from University of Roorkee, MS in computer science and Ph.D. in telecommunications & networking, from the University of Missouri-Kansas City in 1988, 1992, and 1995, respectively. Before joining GSU, he worked as a Research Associate at the Center for Telecomputing Research (funded by Sprint, NorTel, BNR, MCI and State of Missouri) during 1992–1994 and taught at Washburn University, Kansas, during 1994–1998. Prof. Varshney has written over 50 papers in mobile commerce, mobile and wireless networking, wireless dependability, and high-speed networking. He has presented some very well received tutorials and workshops at major international conferences including ACM MobiCom, IEEE WCNC, IFIP HPN, and HICSS. He is also a respected speaker in wireless and mobile networking and applications. He has delivered over 50 invited speeches, including several keynotes at major conferences and workshops. He is actively involved with International Executive education programs at GSU. In October 2000, Prof. Varshney was awarded the prestigious Myron T. Greene Outstanding Teaching Award. He is on the editorial board of IEEE Computer. He has also served on the program committees of IEEE WCNC, IEEE LCN, ACM Workshop on Mobile Commerce, HICSS and several other international conferences. He is a member of ACM and IEEE and several SIGs and societies.
E-mail: uvarshney@gsu.edu

Andrew P. Snow is an Assistant Professor of Computer Information Systems (CIS) at Georgia State University. His primary research interests deal with information systems and telecommunications reliability, availability and survivability, which includes IT infrastructure, wireless and wire-line telecommunication systems. In the wake of 9-11, Snow has been an invited speaker at Columbia University and Nippon Telephone and Telegraph. Snow's work has appeared in the IEEE Transactions on Reliability, Communications of the ACM, the Journal of Network and Systems Management, IEEE Computer, ACM StandardView, and in numerous IEEE conferences and workshops. Prior to becoming an academic researcher and teacher, Snow engineered, designed and implemented line-of-sight microwave, multiplex, and fiber optic systems. In addition, he designed and implemented wide area and local area data networks. He has held a variety of positions, including electrical engineer, member of the technical staff, manager, director, vice president, general manager, and president. Snow's experience also includes consulting, systems integration and project management. As a consultant, Snow's clients included General Electric and Boeing Computer Services. In the latter role, Snow was the successful bidder and project manager for an $80M telecommunications modernization program. Snow earned his bachelor's and master's degrees from Old Dominion University in engineering (electrical), and his doctorate in information science (telecommunications) from the University of Pittsburgh, in 1970, 1972, and 1997, respectively.
E-mail: asnow@gsu.edu