A New Approach for the Betterment of Wireless Network Performance Using Bandwidth Degradation and Ad-hoc Relaying

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ABSTRACT:
With respect to the increasing growth in the subscribers of wireless cellular networks and the necessity of providing network services with reasonable quality in any location, the importance of enhancement in the wireless network services is deeply felt. This means that network users expect to receive voice, data, and multimedia services with reasonable QoS, regardless of their locations and mobility patterns. Therefore, failures which may occur in mobile wireless network and may inhibit communication or result in loss of critical data will be not tolerated. Hence, providing wireless networks services in the presence of network failures has a great importance and can cause the networks to avoid from reducing their subscribers. In this paper, two main schemes are proposed, in order to reduce bad effects, which can be generated for the case of network failures. These schemes try to reduce dropping probabilities and cause mobile hosts in the failed cell to continue their calls with high probability for the case of failure. One of the proposed schemes uses ad hoc relaying and the other uses bandwidth degradation, in order to improve network performance in the case of failure. Simulation results show that these two schemes have great impacts in improving network performance for the case of failure.

KEYWORDS: Ad hoc Relay Station, Survivability, Failure, Bandwidth Degradation, Fault-Tolerant Networks.

1. Introduction

Mobile communications systems experience a rapid increase over the number of subscribers, which places extra demands with different requirements on their capacity [1, 2, 3]. Due to the growing importance of these systems, it is necessary to study their behavior for performance evaluation, optimization, and management, under realistic conditions [4, 5]. With respect to the rapid growth of the mobile wireless networks, the importance of service provisioning with good quality of service (QoS) is strongly felt. This means that network users expect to receive voice, data, and multimedia services with reasonable QoS, regardless of their locations and mobility patterns [6]. Therefore, different failures of a mobile wireless network that may prevent communication or result in the loss of critical data will be not tolerated [6].

The critical importance of providing communication service in the presence of failures has been recognized in the public switched telephone networks (PSTN); However, the unique aspects of wireless access networks (e.g., user mobility, wireless channel, power conservation) suggest that survivability techniques for wired networks may not be directly applicable [6].

With no doubt, in the case of failure in the network, some services and functions being affected by it may not work properly. In order to measure the degree of network survivability against failures, some special metrics quantifying the network operation can be evaluated during the failure scenarios [6]. Different failure scenarios in mobile wireless networks, such as resource faults, link faults, equipment faults, and node faults [7], affect on service provisioning in the network and in the worst case, may cause network not to serve users in some locations. Hence, suggesting new methods, which can provide network services and reduce call dropping rate in the case of different failure scenarios in wireless networks, is a valuable and important work.

In this paper, the main goal is to maintain methods, which can minimize bad effects that network failures put on subscribers and produce network services for a high percentage of the users in the case of network failure. For this goal, two different methods are suggested throughout this paper. These two various methods use different solutions, in order to save active connections from being dropped at the presence of failure in the cell. Since the ongoing connections find it more disturbing to be prematurely dropped than the new connection requests, this paper tries to suggest some novel solutions, in order to reduce undesirable dropping rate in the presence of failure in the cells.

One of the proposed solutions uses ad hoc relaying, in order to serve a high percentage of active connections in the failed cell. The new proposed solution can help a considerable number of active connections to avoid from being dropped. This novel policy can strongly be helpful for the active connections in the failed cell being closer to the boundaries between the failed cell and its adjacent cells. The probability of avoidance from being dropped for the active connections in the failed cell is precisely determined.

Another proposed solution uses bandwidth degradation in the adjacent cells of the failed cell, in order to serve active connections in the failed cell. This policy suggests hand-off to the adjacent cells of the failed one for the active connections in the failed cell. It also offers that the adjacent cells of the failed one can use the bandwidth degradation scheme in the case of bandwidth shortage. Therefore, the adjacent cells of the failed one will be able to serve more hand-off requests from the failed cell. The probability of successful hand-off for the active connections in the failed cell is exactly determined.

In what follows, related works are reviewed in Section 2. Section 3 includes a brief summary about how a cell uses ad hoc relaying, in order to serve the active connections not being in its coverage. Section 4 explains the ad hoc relaying solution for the improvement of undesirable dropping in the presence of failure. Section 5 involves the bandwidth degradation solution for the reduction of premature dropping rate in the failure conditions. Simulation results are presented and analyzed in Section 6. Section 7 includes some concluding remarks.

2. Related works

Several works have been published in the literature in the case of different failure scenarios in wireless networks. These works suggest different methods to manage the network in the case of failure [7-10]. In [7], a specific taxonomy of faults in wireless networks is presented. Three dimensions of faults are considered in [7] including the component affected by the fault, the severity of the fault, and the location of the fault. It considers a fault management system which provides functions such as detection of faults in a network, diagnosis of the fault, and recovery from the fault [7].

In [11], a precise mathematical model is proposed in order to represent the effects of some special failures in wireless cellular networks on the services being delivered to the subscribers. For this purpose, the process of one essential component's failure in the cellular network architecture is considered a Poisson one. In addition, a failure rate and a repair one are defined for the component facing problem. It is discussed that the values of those rates have direct effects on the average number of users waiting for service in the cell. In other words, setting these rates can strongly improve the situation of network in the case of failure [11].

In [8], a neural network is developed, which is trained to investigate availability, reliability, maintainability, and survivability attributes of a wireless network. Component mean time to failure (MTTF) and mean time to restore (MTTR) are used to model the reliability and maintainability, respectively [8]. In [9], a novel network design model is presented that incorporates the effect of user mobility for fault-tolerant wireless access networks. The design of wireless access networks being fault-tolerant is considered as an integer programming model [9].

In [10], several different architectures and methods that can be used in designing survivable wireless networks are proposed. The inverse of component failure rate or mean time between failure (MTBF) is used to understand the behavior of failures. The mean time to restore (MTTR) includes fault isolation, repair/replacement, and testing times [10]. This scheme focuses on larger MTBFs and smaller MTTRs and proposes some strategies to decrease MTTR such as placing redundant components, redundant power and multiple interfaces to access different wireless networks [10].

3. A brief summary about ad hoc relaying

In order to provide survivability in mobile wireless networks, a wireless cellular network is considered, in which a mobile station communicates with others via a base transceiver system (BTS) and each BTS is controlled by a mobile switching center (MSC) [12, 13].

In the several previous works using ad hoc relaying, a number of Ad hoc relay stations (ARSs) are placed at strategic locations [12], which can be used to relay signals between mobile hosts and BTSs. By using ARSs, it is possible to divert traffic from one cell to another [12, 14]. Note that each ARS has two air interfaces, the *C* (for cellular) interface for communications with a BTS and the *R* (for relaying) interface for communicating with a mobile host (MH) or another ARS. Furthermore, MHs should have two air interfaces, the *C* interface for communicating with a BTS, and the *R* interface for communicating with an ARS [12].

A relayed wireless access network (RWAN), is a network in which Mobile Stations (MSs) can access the network via one or more wireless hops [15, 16]. In [16], a self-organizing method is proposed to solve one of the most challenging problems in the network, the high dropping rate of hand-off requests. This method relies on ad hoc relaying, in order to improve the dropping rate in the network. In this solution, the MSs having reasonable distances from ARSs can perform vertical hand-off through relaying and improve the hand-off process in the network.

Definition 1

When an active MH, outside the coverage area of a cell is served by its corresponding BTS through an ARS, the MH is in the relaying mode [17].

Definition 2

The maximum permitted distance between an active MH, in the relaying mode, and its serving ARS is called as the *relaying transmission range* [17].

Figure 1 shows how the ad hoc relaying can help MHs to receive service from a BTS of a cell that is not their own cell. In this figure an MH which its distance from the BTS is greater than R can connect to an ARS and receive service from the BTS, if the total distance from that MH to the BTS is lower than $R + \rho$.

4. Ad hoc relaying solution

In order to make wireless access networks fault-tolerant and survivable, a new solution is proposed in this section which uses ad hoc relaying for improving premature dropping rate of active connections in the presence of failure. It is almost well-known that in order to provide survivability in a system, some level of redundancy is required. This redundancy helps the system to tolerate failures. The proposed solution may reduce some special network benefits to some extent, to provide survivability and fault-tolerance for the network.

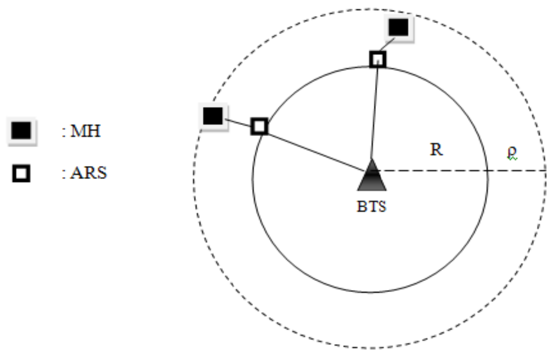

Fig. 1. Ad hoc relaying scheme for helping active users that can not receive service from their original BTSs.

The method which is proposed in this section uses ad hoc relaying, in order to provide survivability in the network and prevent current calls from being dropped in a situation which a problem occurs in the BTS. The structure of a cellular wireless network is shown in Figure 2. For simplicity, the BTS failure in only one cell is considered. This cell and its BTS are called *cell* 1 and *BTS* 1, respectively. The *BTS* 1 serves the MHs being in *cell* 1; however, some failures in the BTS prevent the network from correct performance. In this situation, MHs in *cell* 1 can not receive service from the *BTS* 1. Even with short durations of failures, active connections may be dropped. Since this call dropping is not tolerable for MHs, an *ad hoc solution* is proposed in this section, in order to provide fault-tolerance in the network. To bring a solution for premature dropping reduction in the case of the *BTS* 1's failure, it is possible to divert the traffic from *cell* 1 to adjacent cells. In other words, in the method described here, whenever the *BTS* 1 goes to failure, the MHs in the *cell* 1 try to use ad hoc relaying to avoid from being dropped.

Consider that N MHs receive service from the *BTS* 1. In Figure 2, *cell* 1 is divided to six sectors (*sector* 1… *sector* 6) which there are n_i MHs in *sector* i and Equation (1) is true.

$$N = n_1 + n_2 + n_3 + n_4 + n_5 + n_6 \tag{1}$$

Assume that each MH receiving service in *cell* 1, measures the strength of the received signal from the *BTS* 1. For example, the MH in *sector* 1 is considered. When the *BTS* 1 goes to failure, it gradually senses that the strength of the received signal goes below a certain threshold. Therefore, it decides to use relaying and receive service from the *BTS* 2 through relaying. Assume that the radius of each cell is equal to R and the *relaying transmission range* is equal to ρ. Then, the MHs that are at most $R + \rho$ away from the *BTS* 2 could be served by relaying.

Fig. 2. Cellular wireless network structure.

Assume that when the *BTS* 1 goes to failure, each MH in *cell* 1 senses that the signal strength being received from the *BTS* 1 goes below the minimum threshold. From this moment it has at most t_c seconds to receive service from another BTS and avoid from being dropped. Also, consider that the number of MHs in *sector* 1, which their distances to the *BTS* 2 are less than $R + \rho$, is equal to m_I. Therefore, there are $n_I - m_I$ MHs in *sector* 1, which have distances more than $R + \rho$ from the *BTS* 2.

Consider that MHs in each sector of *cell* 1, moves with constant speed, v. Assume that an MH which its distance from the *BTS* 2 is more than $R + \rho$, is $R + D$ away from the *BTS* 2. If this MH can arrive in *A* area in less than t_c seconds, it can use relaying. Therefore, if inequality (2) is satisfied, the MH that its distance from *BTS* 2 is equal to $R + D$ can arrive in the *A* area, in less than t_c seconds. In other words, it can receive service from *BTS* 2 before losing his connection.

$$\frac{(R+D)-(R+\rho)}{v} = \frac{D-\rho}{v} \leq t_c \quad (2)$$

Assume that the number of MHs which can arrive in the *A* area in less than t_c seconds is equal to m_{II}. Therefore, there are totally $m_I + m_{II}$ MHs in the *A* area, in less than t_c seconds from the moment of the *BTS* 1's failure.

The proposed solution is to place a reasonable number of ARSs in the strategic locations, in order to help active connections in the failed cell. The strategic locations in this case are in the places being closer to the common lines between the *cell* 1 and its adjacent cells. The active connections in the failed cell should have a distance smaller than $R + \rho$ from the adjacent BTSs, in order to receive service from them. These active connections can connect to ARSs through ad hoc relaying. In this situation, if the adjacent cells of the failed cell have enough free channels, they can serve active connections from the failed cell.

Suppose that the *cell* 2 and other adjacent cells of the *cell* 1 are divided to six sectors. Assume that there are s_I ARSs in the *sector* 11 which may be helpful for the active connections in the failed cell. Notice that if these ARSs are closer to the common line between the *cell* 1 and the *cell* 2, they can strongly help the active connections in the *cell* 1. Note that each of the MHs in the *A* area should connect to an ARS with suitable distance, in order to receive service from the *BTS* 2. It should be considered that the adjacent cells, for example *cell* 2 in this case should have enough free channels, in order to serve some requests through relaying. In other words, if the adjacent cells are so crowded that there is no free channel in them, no ARS can receive service from the adjacent BTSs and no active connection in *cell* 1 can avoid from being dropped.

Now, with the above assumptions, the probability of successful relaying for the MHs in the *sector* 1 is calculated for different cases.

If the number of ARSs in the *sector* 11, s_I, is greater than the number of the MHs in the *A* area, $m_I + m_{II}$, then there are more than one option for each MH to choose as an ARS. In this case, each of the MHs in the *A* area, can choose the most suitable ARS and continue its call successfully. Therefore, the probability that $m_I + m_{II}$ MHs in the *sector* 1 continue their calls successfully, P_I, is given by (3).

$$P_1 = \binom{n_1}{m_1 + m_{11}} p_b^{\,m_1+m_{11}} (1-p_b)^{n_1-(m_1+m_{11})} p_c(m_1 + m_{11}) \quad (3)$$

where, $m_I + m_{II}$, is the number of MHs in the *A* area which want to perform relaying. n_I, is the number of MHs which are in *sector* 1 when the *BTS* 1 goes to failure. p_b, is the conditional probability of being in the *A* area due to being in *sector* 1 and is calculated here. $p_c(m_I + m_{II})$, is the probability that at least $m_I + m_{II}$ channels in cell 2 are free and is determined later.

First of all, the space of the *A* area should be determined, in order to calculate p_b. Note that the *A* area can be approximated with a trapezoid, which one of its trapezoidal rules is equal to *R*, and the trapezoidal height, *h*, is calculated with (4).

$$h = R\left(1 - \frac{\sqrt{3}}{2}\right) + \rho \quad (4)$$

where, *R* is the cell radius, and ρ, is the *relaying transmission range*. Also, the value of the other trapezoidal rule, *d*, is calculated with (5)

$$d = \frac{2\sqrt{3}}{3}\left[R\sqrt{3} - (R + \rho)\right] \quad (5)$$

where *R* and ρ were introduced previously. Therefore, the space of the *A* area, *S*, is calculated by (6).

$$S = \frac{h(d+R)}{2} \quad (6)$$

Hence, the conditional probability of being in the *A* area due to being in the *sector* 1, p_b, is approximately determined by (7).

$$p_b = \frac{2\sqrt{3}}{3}\frac{h(d+R)}{R^2} \quad (7)$$

Where *R*, *d*, and *h* were introduced previously. In order to determine p_c, it is considered that in *cell* 2 (or other adjacent cells of *cell* 1), the BTS serves requests with exponential distribution with rate μ, and it doesn't consider any priority for hand-off requests. There are *M* channels in each cell, and requests arrive in the cell with Poisson process with rate λ. A Markov chain can model the performance of adjacent BTSs of *BTS* 1. This Markov model is shown in Figure 3. We should calculate the probability that at least $m_I + m_{II}$ channels are free in *cell* 2, in order to determine p_c.

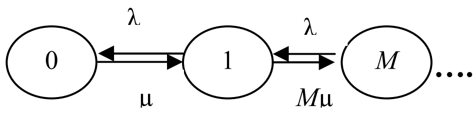

Fig. 3. A Markov model showing the performance of *BTS* 1,…, *BTS* 7 in the ad hoc relaying solution

Considering this Markov model, the probability that at least $m_1 + m_{11}$ channels are free in each cell, $p_c(m_1 + m_{11})$, is determined by Equation (8).

$$p_c(m_1 + m_{11}) = P_0 + P_1 + \cdots + P_{M-m_1-m_{11}} = \frac{\sum_{i=0}^{M-m_1-m_{11}} \frac{1}{i!}(\frac{\lambda}{\mu})^i}{\sum_{i=0}^{M} \frac{1}{i!}(\frac{\lambda}{\mu})^i} \quad (8)$$

where, P_i (for i =0, 1,…, $M - m_1 - m_{11}$) shows the probability that i channels are occupied in a cell. M, λ, and μ were introduced previously.

Now a different case is verified in which the number of ARSs in the *sector* 11, s_1, is equal to the number of MHs in the *A* area, $m_1 + m_{11}$. In this case for each of $m_1 + m_{11}$ MHs, there is only one option to choose as its ARS and continue its call successfully. Therefore, the probability that $m_1 + m_{11}$ MHs in the *sector* 1, continue their calls successfully even in the failure conditions of the *BTS* 1, P_1, is given by following equation.

$$P_1 = \binom{n_1}{s_1} p_b^{\,s_1}(1-p_b)^{n_1-s_1} p_c(s_1) \quad (9)$$

where, s_1 is the number of ARSs in the *sector* 11 and n_1 and p_b were introduced in Equation (3) and Equation (7), respectively. $p_c(s_1)$, is the probability that at least s_1 channels in the adjacent cells of the *cell* 1 are free and is calculated in a similar way that $p_c(m_1 + m_{11})$ was determined in (8). Finally, if the number of the ARSs in the *sector* 11, s_1, is less than the number of MHs in the *sector* 1, $m_1 + m_{11}$, then only s_1 MHs can connect to the ARSs and use relaying. Hence, the probability that s_1 MHs in sector 1 continue their calls successfully through relaying, P_1, is given by (9). It can be said that the probability that c_1 MHs in *sector* 1 perform relaying successfully and avoid from being dropped, is determined by one of Equation (3) or Equation (9) based on a comparison between $m_1 + m_{11}$ and s_1. Note that c_i, is determined with (10).

$$c_i = \min(s_i, m_i + m_{ii}, h_{i+1}) \qquad for\ i = 1\ to\ 6 \quad (10)$$

where, s_i, is the number of ARSs in the *sector ii* from the adjacent cell having common boundary with *sector i* from *cell* 1. h_{i+1} is the number of free channels in *cell* $i + 1$ at the moment of the *BTS* 1's failure. $m_i + m_{ii}$, is the number of MHs in the *sector i* of *cell* 1 at the moment of the BTS 1's failure. Note that these equations can be determined for the other sectors in a similar way. P_i, shows the probability that c_i MHs in *sector i*, perform relaying successfully and continue their calls without any problem. Note that c_i and P_i are determined with (10) and (11), respectively.

$$P_i = \binom{n_i}{c_i} p_b^{\,c_i}(1-p_b)^{n_i-c_i} p_c(c_i) \quad (11)$$

Therefore, the probability that n MHs in the *cell* 1 perform relaying successfully and continue their calls, P, is determined by (12).

$$P = \sum_{i=1}^{6} P_i\, P_s(i) = \frac{1}{6}\sum_{i=1}^{6} P_i \quad (12)$$

where, $P_s(i)$, is the probability of being in *sector i*, and is equal to $\frac{1}{6}$ for each sector. Note that n is equal to the sum of the number of MHs which can perform relaying successfully in different sectors and is given by (13).

$$n = \sum_{i=1}^{6} c_i \quad (13)$$

5. Bandwidth degradation solution

In this section, bandwidth degradation scheme is used in the adjacent cells of *cell* 1, in order to serve MHs of *cell* 1 which can't receive service from the *BTS* 1, because of its failure. Initially it should be noted that the idea of bandwidth degradation is considerably used in the case of resource shortage in wireless access networks [18, 19]. First, the bandwidth degradation scheme is discussed.

Consider that the BTS in each cell possesses a limited amount of bandwidth, which is called BW. Also assume that for each call three kinds of bandwidth, $\{B_{max}, B_x, B_{min}\}$, could be considered [3]. Note that B_{max}, is the ideal bandwidth for each call, which can provide the best quality for the connection. B_{min}, is the minimum bandwidth, which can provide reasonable quality for the calls, and if an MH requests a call when the available bandwidth in the cell is lower than B_{min}, the request is rejected. Finally, B_x, is a value between B_{min} and B_{max}. Note that the BTS in a cell can simultaneously serve at most M MHs with B_{max} and equation (14), is true [5].

$$BW = MB_{max} \quad (14)$$

For more verification of this scheme, consider Figure 4. In this figure, the BTS of *cell* 1, (which is called the *BTS* 1), sometimes goes to failure. If the *BTS* 1, goes to failure, some MHs which are near to adjacent cells (*cell* 2,…, *cell* 7), try to perform hand-off to the adjacent cells. The MHs in *cell* 1, has at most t_h seconds to perform hand-off, from the moment they sense the signal strength is going lower than a minimum threshold. Consider that the coverage area of *BTS* 2 in cell 1, is the *a* area. Therefore, if the MHs are in the *a* area at the moment of *BTS* 1's failure, or they can arrive to this area in less than t_h seconds, then they have the opportunity to perform hand-off successfully.

For the hand-off process verification, the worst case in *cell* 2 (and other adjacent cells of the *cell* 1) is considered. In this case, when the *BTS* 1 goes to failure, the *BTS* 2 is serving to the MHs with its total capacity and *M* MHs are receiving service with B_{max}. Then, the *BTS* 2 degrades the bandwidth of some of its users from B_{max} to B_{min}, in order to serve hand-off requests from the *cell* 1.

Assume that the hand-off and new call requests to *cell* 2, are generated with Poisson process with rate λ_h and λ, respectively. Also the *BTS* 2, serves to the users with exponential process with rate μ. Note that *BTS* 2 performs bandwidth degradation only for the hand-off requests from the *cell* 1. Also assume that the MHs in *cell* 1, make the hand-off requests with Poisson process with rate λ_h, at the moment they sense their signals strength is going lower than the minimum threshold.

The state transition diagram for *cell* 2 is shown in Figure 5. In this figure, in the state (n, m), n shows the number of MHs in *cell* 2, which receive service with B_{max} and m shows the number of MHs in *cell* 2, which receive service with at least B_{min}. If in state (M, 0), any hand-off request from *cell* 1 arrives in *cell* 2, the *BTS* 2 degrades the bandwidth of

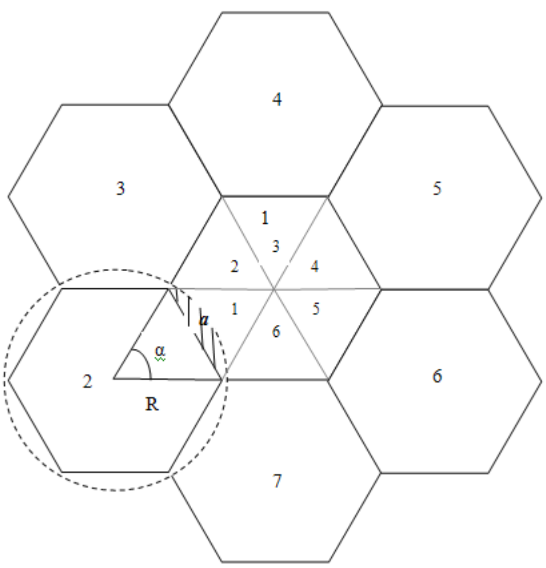

Fig. 4. The structure of cellular wireless networks indicating the coverage area for hand-off requests.

b MHs from B_{max} to B_{min}, in order to serve new hand-off request. Therefore, it serves to $M - b$ MHs with B_{max} and $b + 1$ ones with B_{min}. In order to make this bandwidth degradation scheme possible, inequality (15) should be satisfied.

$$B_{max} \geq (1 + \frac{n_1}{b}) B_{min} \tag{15}$$

Where, B_{max} is the ideal bandwidth for each connection and B_{min} is the minimum reasonable bandwidth for making a connection. b, is the number of connections losing some parts of their bandwidth with the advent of any hand-off request from *cell* 1 and n_1, is the number of hand-off requests from *cell* 1 which can receive service from one of the adjacent cells.

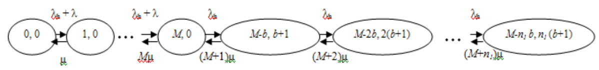

Fig. 5. Markov model for the channel allocation in the adjacent cells of *cell* 1 in the second solution

The *BTS* 2 performs this bandwidth degradation scheme, in order to serve hand-off requests from *cell* 1. In other words, the *BTS* 2 gives priority to the MHs, which want to perform hand-off because of the *BTS* 1's failure, rather than other hand-off requests. Note that the *BTS* 2, can serve at most n_1 hand-off requests from *cell* 1 in the bandwidth degradation scheme (in addition to *M* MHs). Therefore, at most n_1 MHs can perform hand-off successfully from *cell* 1 to *cell* 2.

Assume that there are totally *N* MHs in *cell* 1, which receive service from the *BTS* 1 before its failure. The *cell* 1 is divided into six sectors and N_i MHs exist in *sector i*, at the moment of the *BTS* 1's failure. The adjacent cell which has common boundary with *sector i* of the *cell* 1, can serve to at most n_i hand-off requests from *sector i* of *cell* 1. Assume that the value of N_i is greater than n_i. Therefore, the probability that n_i mobile hosts in sector i, can perform hand-off successfully to cell $i + 1$, P_i, is given by (16).

$$P_i = \binom{N_i}{n_i} {p_a}^{n_i} (1 - p_a)^{N_i - n_i} \tag{16}$$

where, n_i, is the number of hand-off requests which cell $i + 1$ can serve from *sector i* of the *cell* 1. N_i, is the number of the MHs in the sector i from *cell* 1, at the moment of the *BTS* 1's failure. p_a, is the conditional probability of successful handoff due to being in the *a* area and is determined by (17).

$$p_a = p_0 \sum_{x=0}^{n_i} P\big(M - xb, x(b+1)\big) \; for \; i = 1 \; to \; 6 \tag{17}$$

where, p_0, is the probability of being in the *a* area and is determined in (18). $\sum_{i=0}^{n_i} P\big(M - ib, i(b+1)\big)$, is the probability that the hand-off request can receive service from cell $i + 1$. M is the number of active MHs in cell $i + 1$, which can receive service with B_{max}, simultaneously. b, is the number of MHs which the $BTS\ i+1$ degrades their bandwidths with the advent of each hand-off request from $sector\ i$ of the $cell$ 1. n_i was introduced in (16).

$$p_0 = \frac{the\ space\ of\ a\ area}{the\ space\ of\ sector} = \frac{2\sqrt{3}}{3}(\alpha - \sin\alpha) \quad (18)$$

where, α, is the angle being shown in Figure 4 and is determined in radian. Hence, the probability that n MHs perform hand-off successfully from *cell* 1 and continue their calls, P_h, is given by (19). Notice that n is calculated by (20).

$$P_h = \sum_{i=1}^{6} P_i\, P_s(i) = \frac{1}{6}\sum_{i=1}^{6} P_i \quad (19)$$

where, $P_s(i)$, is the probability of being in *sector i*, and is equal to $\frac{1}{6}$ for each sector. P_i, is the probability of successful hand-off in each *sector i* and is determined with (16).

$$n = \sum_{i=1}^{6} n_i \quad (20)$$

Where, n, is the total number of MHs which can perform hand-off to the adjacent cells of cell 1 in the case of failure. Also, n_i, is the number of MHs that can perform hand-off from sector i of cell 1 to cell i + 1. Note that it can be considered that there is a queue of hand-off requests, near each of the adjacent cells of *cell* 1 (*cell* 2,…, *cell* 7). The average number of the MHs in the queue of each *sector i*, N_{Q_i}, is determined by (21).

$$N_{Q_i} = \sum_{x=0}^{n_i-1}(n_i - x)P\big(M - xb, x(b+1)\big) \quad for\ i = 1\ to\ 6 \quad (21)$$

where, n_i and b, were introduced in Equation (16) and Equation (17), respectively. Hence, the average amount of waiting time in the queue of *sector i* from the *cell* 1, is determined by following equation.

$$W_i = \frac{N_{Q_i}}{\lambda_h} \quad (22)$$

Therefore, it can be concluded that t_h, the maximum time that each MH in *sector i* of *cell* 1 possesses to perform hand-off, should be greater than W_i. In other words, inequality (23), should be satisfied.

$$t_h \geq W_i \quad for\ MH\ in\ sector\ i \quad (23)$$

6. Simulation results

In order to simulate the performance of the proposed schemes, a simulator has been developed. In order to simulate the first solution (using ad hoc relaying to reduce dropping probability in the case of BTS's failure), an area is considered which is like as Figure 2. The procedure is as follows. For each cell, n channels are considered which can serve to hand-off and new call arrival requests. There are totally N MHs which are distributed randomly among the whole area. Some of these N MHs are active mobile stations which are receiving service in each cell (Note that the number of active mobile stations in each cell is between 0 and n), and the remainder of them are inactive MHs which can be used as ARSs. Therefore, each time that simulator is executed, a random number is generated as active MHs for each cell. This random number is k_i for cell i and hence, there are $N - \sum_{i=1}^{7} k_i$ inactive MHs in the whole area which can be used as ARSs. The number of active MHs in each sector of the *cell* 1 is determined and the number of free channels in the corresponding adjacent cells for each sector is calculated with a program. Therefore, it can be said that if there are enough inactive MHs in suitable distances from active ones and if the adjacent cells have enough free channels, it can be possible for active mobiles to avoid from being dropped in the presence of failure in *cell* 1.(Note that the failure of BTS is considered only in cell 1 and the adjacent BTSs have no problem). In addition, notice that simulator has been run for a simulation time being equal to 100,000 units of time.

In order to simulate the bandwidth degradation solution, for each cell a random number is generated which shows the number of active MHs in that cell. Then, the number of MHs which is placed in the *a* area (which is illustrated in Figure 4), is determined. If the number of free channels (taking into account bandwidth degradation) in adjacent cells is equal or greater than the number of active MHs in the *a* area, they can be served by adjacent BTSs in the case of *BTS* 1's failure.

Table 1. The values of parameters which are used in simulation models.

N	Λ	λ_h	μ	*M*	*R*	P
1000	0.1	0.01	0.01	53	100	60

Simulation results are shown in Table 1, Figures 6, 7, 8, 9, 10, 11. Table 1 shows the values of parameters which are used in simulation models. Note that in each experiment the value of one parameter changes from its original value which is illustrated in Table 1. Afterwards, the impact of this change on the network performance is evaluated. Figure 6 shows the average number of active MHs in *cell* 1 versus different values for new call arrival rate (λ) in both solutions. As it is expected, when new call arrival rate is increased, more MHs new make connection requests; Therefore, the average number of active MHs in *cell* 1 and the number of occupied channels in *cell* 1 are increased, consequently. Note that with increment in the λ, the average numbers of active MHs in *cell* 1 reaches its maximum (*n*) and the total available channels in this cell are gradually occupied. The two trends are similar and both the solutions show same behavior in this case, clearly.

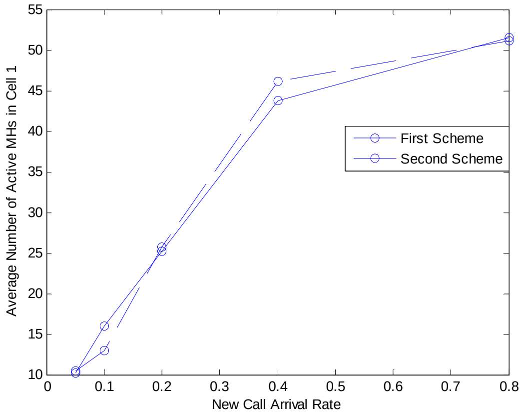

Fig. 6. Average number of active MHs in *cell* 1changing with new call arrival rate

Figure 7, shows the average number of active MHs in *cell* 1 versus different values for call duration in both the solutions. Note that call duration is equal to the inverse of call service rate (μ). As it is expected, when call duration is increased, the active MHs stay in the cell more lastingly, and with the same new call arrival rate (λ), there would be more active MHs in the cell. Note that the average number of active MHs in *cell* 1, gradually reaches to the number of total available channels in the cell (*n*).

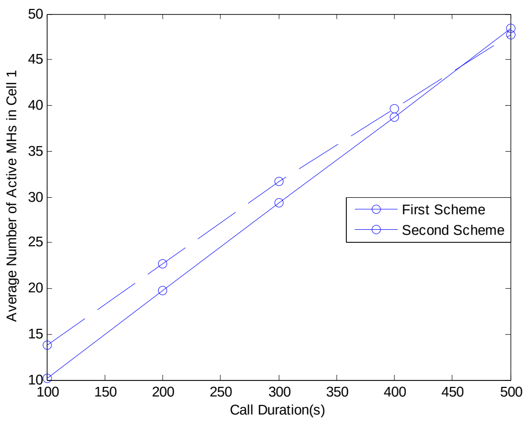

Fig. 7. Average number of active MHs in *cell* 1 changing with call duration

Figure 8, shows the average distance from the center of the *cell* 1 for active MHs in this cell versus different values for cell radius (R) in both the solutions. Note that as it is expected, with increment in the cell radius, the average distance from the center of the cell is increased and both the solutions show approximately similar behavior in this case.

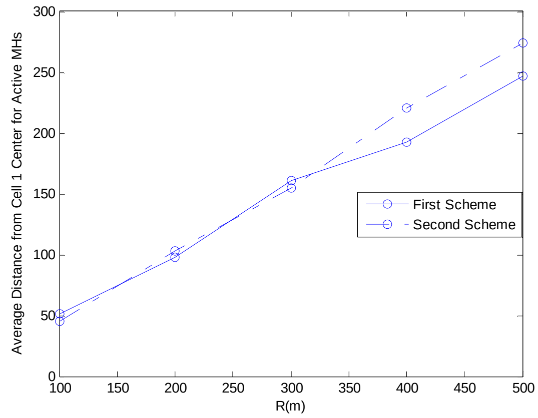

Fig. 8. Average distance from the center of *cell* 1 for active MHs changing with cell radius

Figure 9 shows the number of inactive MHs that can be used as ARSs versus different values for call duration. Note that these MHs are placed in suitable distance from active MHs and if the adjacent cells have free channels, they can protect the active MHs from being dropped in the case of *BTS* 1's failure. As it is expected, with increment in the call duration time, the average number of active MHs is increased according to Figure 6. Since the sum of active and inactive MHs which is distributed in the whole area is constant and equal to *N*, increment in the number of active MHs, would result in decrement in the number of inactive MHs (which can be used as available ARSs).

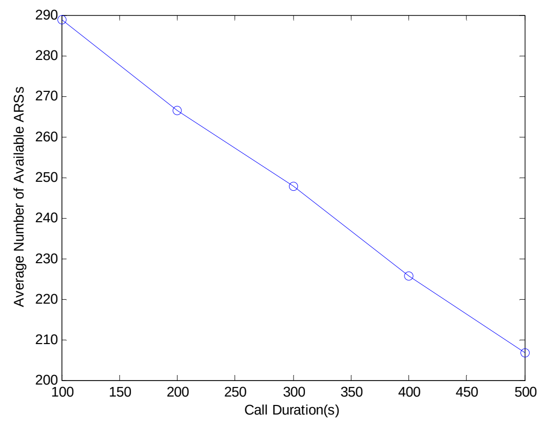

Fig. 9. The average number of available ARSs versus call duration time

In order to determine the success percentage of the proposed solutions, a metric is defined here which mathematically measures the success being obtained by the proposed solutions.

Definition 3.
The ratio of the number of active MHs being in *cell* 1 which can continue their calls successfully in the case of BTS 1's failure to the number of total active MHs in *cell* 1 in the case of failure is defined as success ratio.
Figure 10, shows the success ratio versus different values for relaying transmission range (ρ) in the ad hoc relaying solution. As it is expected, with increment in the ρ, more ARSs can be located in suitable distance from active MHs. Therefore, more active MHs can use relaying, in order to reduce dropping rate. Hence, the success ratio is improved.

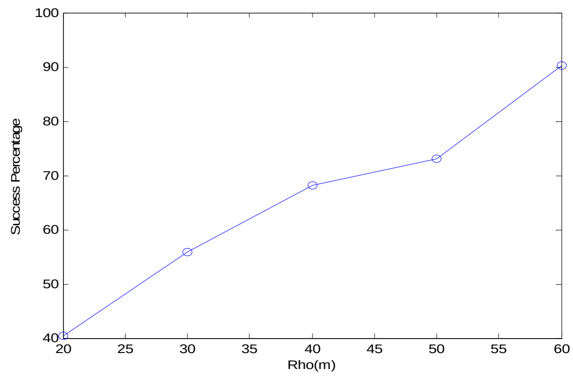

Fig. 10. Success ratio versus relaying transmission range (ρ)

Figure 11, shows the success ratio versus different values for new call arrival rate (λ) in the ad hoc relaying solution. As it is expected, with increment in the new call arrival rate, the average number of active MHs in th cell 1 is increased and in the case of failure in BTS 1, there are more MHs in cell that require to use relaying, in order to avoid from being dropped. Since the number of available ARSs is constant here, the success ratio is decreased with increment in the new call arrival rate.

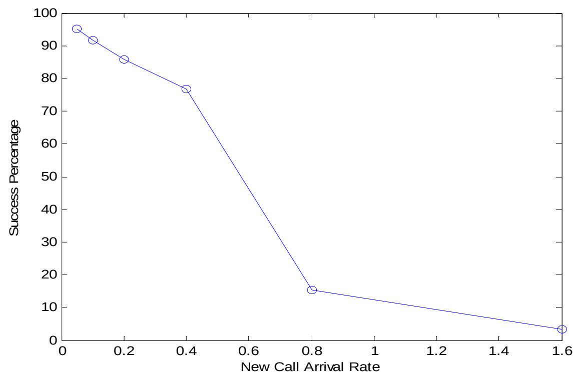

Fig. 11. Success ratio versus new call arrival rate (λ)

7. Conclusions
With the astonishing growth of the wireless cellular networks' subscribers, they expect to receive service with better QoS. In addition, they can not tolerate the networks' failures which may cause undesirable dropping of their connections. In order to solve this problem, in this paper, two solutions were proposed to improve the network performance in the case of a failure occurring in a BTS of a cell. These two solutions use different methods, in order to help active connections in the failed cell; however, they both try to reduce the premature dropping rate in a cell in which BTS's failure occurs. One of the solutions uses ad hoc relaying, in order to serve some MHs in the failed cell via several active relay stations. The other one, suggests performing hand-off to the adjacent cells of the failed cell, and also uses bandwidth degradation in the adjacent cells. Simulation results show that both the schemes improve the network performance in the case of failure.

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