Scientific Research and Essay Vol.3 (10), pp. 460-466, October 2008
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 © 2008 Academic Journals

Full Length Research Paper

A paging design for mobile cellular internet enhanced by locality in user-behavior

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Accepted 29 September, 2008

Mobile wireless communication is growing in scope and importance all around the world. The IP network is fast becoming the global network of choice for multimedia communications. Mobile IP network is also fast making its way to the consumer market. However, efficient and scalable mobility management is a key enabler in the mobile IP networks. Secondly, mobile terminals are portable devices that often depend on battery power; they therefore require efficient power management in order to prolong battery life. Paging is an important mobility management function that, not only helps to reduce location update cost, but also helps to conserve mobile terminal battery power. Therefore, efficient paging design is necessary for reliable IP mobility management. Several paging algorithms have been proposed in the literature. These proposals, while generally achieving the overall aim of terminal power conservation, differ in the balance between the amount of delay incurred to locate a given mobile node and the bandwidth cost incurred. This paper provides a paging design for cellular mobile Internet based on the architecture of CHIMA (a Completely Hierarchical IPv6-based micro mobility Management Architecture). The paging algorithm took advantage of the locality in user behavior to achieve a fast and sequential mobile node tracking, which considerably reduced bandwidth and delay costs.

Key words: Mobile communications, mobile IP, paging, resource management.

INTRODUCTION

Mobile wireless communication is growing in scope and importance all around the world, and IP network is fast becoming the global network of choice for multimedia communications. Mobile IP network is also fast making its way to the consumer market. However, without efficient and scalable mobility management and mobility management functions such as efficient and scalable paging procedure, the network will fail to deliver a satisfactory performance. Secondly, mobile terminals are portable devices that are battery powered and therefore, require efficient power management. Paging is an important mobility management function that plays the dual role of helping to reduce location update signaling cost, which improves network scalability, and also helping to conserve mobile terminal battery power, which increases the convenience level of mobile devices and enhances their usefulness.

Wireless mobile communication introduces a considerable amount of signaling traffic in the network. This is because the network uses signaling to keep track of mobile nodes' (MN) locations in the network. This mobile node tracking is very necessary in order for the network to be able to timely locate, and deliver information to MNs. The tracking process requires a MN to register its location with the network nodes, and to regularly update its location information with the network. This process however, consumes both the MN's and network resources. Frequent registration and location information updating consumes MN's power. It consumes network bandwidth in the air interface and on the wired portion of the network, it also consumes computational and storage resources on network nodes.

In order to reduce the consumption of network resources due to MN tracking, mobile networks implement paging. Paging enables the MN to be in either active or passive/standby mode. The MN is said to be in active mode when it is actively communicating with the network. When in this mode, the MN's power consumption is high. When the MN is not actively communicating with the network, it goes into standby state and thus turns its power consumption low. The MN still updates the network with its location information but less frequently. Thus, this mode helps to prolong the MN's battery life. The network has only a vague idea of the MN's location. When information comes for the MN in standby mode, the network performs a search for the MN in order to find its exact location. This search is called 'paging' in mobile networks. This is done by polling all or selected groups of cells in the network. The network node in the cell where the MN is residing then replies to the poll.

Paging process conserves MN's battery; however, it also introduces some cost in the network in terms of bandwidth consumed for polling, both in the air interface and the wired portion of the network, and in terms of the delay incurred in locating a MN before information is delivered to it. If paging is performed at small granularity, say one cell at a time, this minimizes the average cost on network bandwidth but will maximize the average delay incurred before a given MN is located. On the other hand, if paging is performed on large granularity, say polling all the cells at the same time, this will minimize the delay incurred before a MN is found but will maximize bandwidth consumption. Both bandwidth and time are important network resources.

To resolve this two conflicting issues, researchers have taken to developing algorithms that tend to reduce the bandwidth consumption (Ved Kafle et al., 2003; Kyoungae et al., 2004) and at the same time reduce the delay (Goodman, 1996; Rose and Yates 1995) in locating a MN. Such algorithms are usually complex and therefore introduce another cost function in terms of difficulty in implementation, and high cost of computational and storage resource in the network nodes. In mobile telephone networks, paging algorithm is designed with respect to a given location update algorithm. Some of the location update algorithms in literature include the time-based, the movement-based, distance-based, state-based algorithms (Bar-Noy et al., 1995; Naor and Levy, 1999) etc.

In mobile IP networks however, paging algorithm design and performance depends, among other things, on the network architecture. This means that a given network architecture may better support cost-effective paging algorithm than another. There are also two categories of mobile IP network architecture: the macro-mobility management architecture such as the MIP (Perkins, 2002) and the MIPv6 (Johnson and Perkins, 2001), and the micro-mobility architecture such as the cellular IP (Campbell et al., 2000), Hawaii (Ramjee et al., 1999) HMIPv6 (Soliman et al., 2001) etc. Paging algorithms have been designed based on some of these architectures (Castellucia, 1999; Ramjee et al., 2001). However, none of these paging algorithms made use of MN location probability to reduce MN-search cost and complexity.

The cost of locating a MN in standby mode will be greatly reduced if the network has some knowledge of where the MN could be at a given time. This paper took advantage of the locality in mobile user behavior (Kirby, 1995) to design a simple and cost-effective paging algorithm. The author is currently completing a survey on the mobility pattern of mobile users in Nigeria. The result is confirming the observations made in similar surveys in other environments like US and UK, which shows that mobile users move about most often in their region of residence or vicinity of their working environments. It has been also observed that users often do not live very far from their offices/working places. All these imply that in cellular mobile networks, users are most often located in their home cells or neighboring cells. The knowledge of this user behavior is very useful in the design of cost-effective and less complex paging algorithm.

The rest of this paper is organized as follows: Section 2 presents the paging protocol; Section 3, the paging algorithm; Section 4, the performance analysis; Section 5, results and discussion, while the paper is concluded in section 6.

PAGING PROTOCOL

Our paging design is based on CHIMA (Completely hierarchical IPv6-based micro Mobility Architecture) (Onwuka and Niu, 2004). CHIMA is a domain-based micro mobility protocol which, besides being completely hierarchical, also utilizes a hybrid of prefix and host-based routing techniques to achieve a scalable mobile wireless Internet solution. The basic design of CHIMA makes provision for a simple, scalable, and cost-effective paging service. This is because, unlike other Internet micro mobility architectures in literature, CHIMA pushed complex network functions to the edge, thus making it easy to add new systems and services without degrading performance Figure 1.

The paging function is implemented in the SDR. A mobile node that is at home cell, and that has not transmitted packets for a period of time, say, 30 s, goes into a sleep mode. When this happens, a Rest packet is transmitted to the SDR via the home Access Router (AR). On reception, the SDR will enter the MN into a paging list. The home AR will activate the REST field on the MN's record, and forward the Rest packet to the SDR. When a packet originates for a MN in its home cell, the home AR checks the status of the MN, if it is AWAY or at REST, the home AR will route the packet upwards to the SDR. If the MN is in the paging list of the SDR, the SDR will initiate the paging process to locate the MN. Each SDR is responsible for paging all dormant MNs in its coverage area, this means that paging load is distributed and localized, and also, the ARs, which act as home agents (HA), are not further burdened with paging functions. This arrangement ensures load distribution in the access network, and therefore increases the efficiency.

When a mobile node is visiting in a subdomain other than its home subdomain, and goes into sleep-mode, it transmits the Rest packet to the serving SDR via the serving AR. A MN in the sleep-mode is required to periodically refresh the SDR with the sleep-mode status

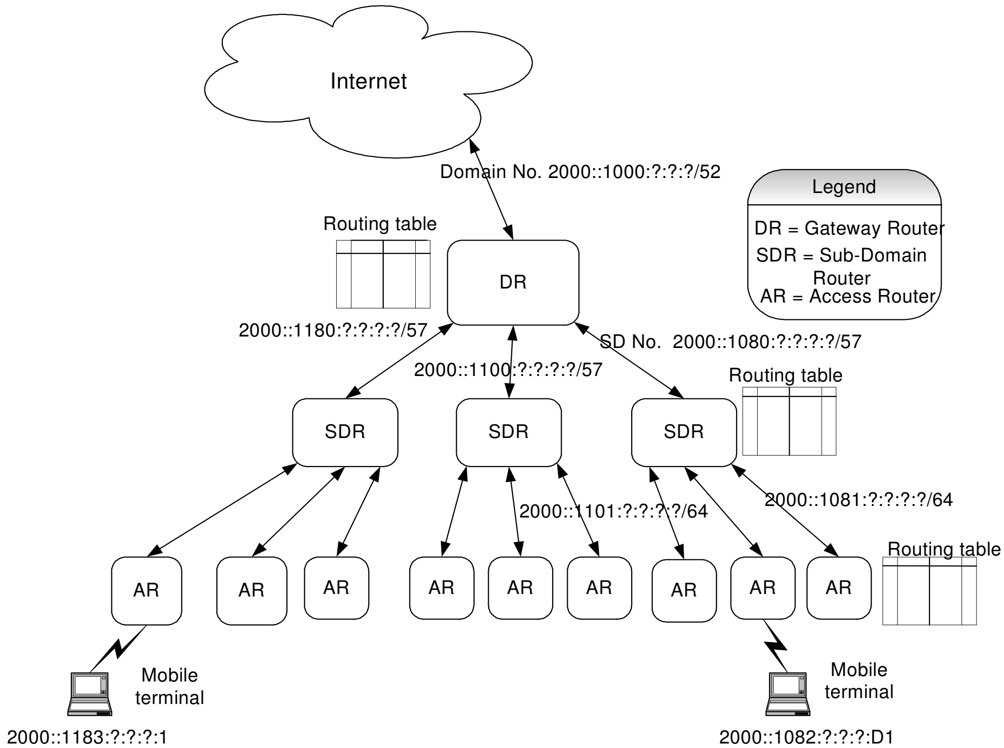

Figure 1. Basic architecture of CHIMA.

with a period quite longer than the active MN refresh period. When packet arrives for him in this foreign subdomain, the serving SDR will initiate the paging process. The steps taken to page a MN is described under the paging algorithm in the next section.

PAGING ALGORITHM

There are three basic categories of paging algorithms in the literature; they are the blanket polling, the fixed paging area concept, and the dynamic paging area concept. Each of these categories introduces some costs either in the form of bandwidth consumption, delay, or complexity. Usually, the authors assume a given mobility pattern for the users. Blanket polling method requires that to locate a MN in sleep-mode, the whole network cells are polled simultaneously. This contributes the minimum delay in locating a MN, and the least location updating cost. But it is prohibitively costly in bandwidth consumption.

The fixed paging concept requires that the network area be divided into paging areas (PA). When a MN in sleep-mode crosses a paging area boundary, it should update the network with location information. When packet arrives for this MN, the network polls the PAs sequentially in search of the MN, when the MN is located, the search stops. There are various configurations proposed in literature for polling the PAs. This method has the advantage of reducing the bandwidth consumption due to polling, but it introduces increased update cost. The update cost depends on the granularity of the PAs. Large PAs will contribute less update cost but will increase bandwidth consumption. Small PAs will contri-bute high update cost but less bandwidth cost. The amount of delay introduced by this method depends primarily on the algorithm used in selecting which PA to poll first and which one to poll next. The research solutions here aim at getting optimum size of PAs and at developing the algorithm that locates the MN faster.

The dynamic paging area concept argues that the fixed PA methods are not sufficiently efficient, because PA sizes are determined based on such individual activities as packet arrival rate, mobility rate, mobility pattern, and call arrival rates. But these activities are not the same for all MNs. Therefore, the dynamic paging area category develops algorithms that configure a PA for each MN based on its mobility pattern, packet arrival rate and mobility rate (Wan and Lin, 1997). This category of paging algorithms utilizes network resources more efficiently, but has the disadvantage of increased complexity which may impact on implementation cost. It may also be difficult to implement dynamic PA schemes in cellular networks where network nodes are designed to perform network function with respect to given network zones or coverage areas.

To improve the paging efficiency with a less complex algorithm that conveniently fits into the regular cellular system, our algorithm uses a hybrid of fixed paging area

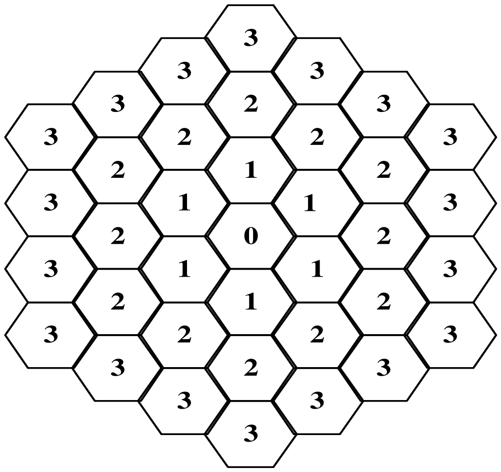

Figure 2. Cell arrangement for a fixed PA.

(FPA) concept and the dynamic paging area (DPA) concept. The method employed in searching a MN in sleep-mode is simple and efficient and it is as follows: The network wide concept of paging area is fixed. Each subdomain constitutes a paging area, and contains a variable number of cells, arranged in a circular cluster as shown in Figure 2 (Akyildiz and Wang, 2002). The SDR maintains the paging list and pages any MN in its paging area. Whenever, a MN in sleep-mode crosses a FPA boundary (in this case a subdomin boundary), it is required to send a location update to the SDR in the new subdomain. Each FPA is further divided into conceptual DPAs for each MN. These DPAs consist of the home cell of each MN and the neighboring cells, which are the rings of cells surrounding it in the subdomain. The DPA for each MN is derived from the concept of locality in mobile user behavior. According to the locality concept, with a high probability, MNs move about within their home cells or its neighborhood (Kirby, 1995). Based on this, when packets arrive for a MN in sleep-mode, the SDR pages selected groups of cells in the FPA sequentially, starting from the cell where the MN is most likely to be found, and progresses in a decreasing order of the probability of where the MN could be located. It starts by paging the home cell of the MN, say, cell 0 in Figure 2. If the MN is not found, the next neighbor, which is the ring of cells numbered 1, are paged. Then the next ring, numbered 2 is paged. After the second ring of cells is paged without success, the rest of the cells in the FPA are paged. Analysis shows that the MN will most likely be found after the first two polls. This algorithm is simple and cost-effective as we are going to demonstrate in this paper.

PERFORMANCE EVALUATION

In this section we carry out an evaluation of our hybrid paging algorithm. Our aim is to demonstrate the effect of paging according to the locality probability. We do this by estimating the bandwidth cost of location update and paging both in the wired and wireless links of the access network. So the total cost is given by

$$C = C_p + C_u$$

Where C_p is paging cost ad C_u is update cost.
To estimates these costs, we define the following variable:

- C_w = bandwidth cost on wireless link
- C_l = bandwidth cost on the wired link
- λ = rate of session arrival
- α = No of times a MN goes to sleep-mode per unit time
- ρ = MN density per unit area

We also make the following assumptions for the locality probability *p*:

- The probability that a MN is in its home cell, at D = 0 is $p_1 = 0.5$
- The probability that the MN is in its nearest neighborhood, i.e., within the ring D = 1, is $p_2 = 0.3$
- The probability that the MN is in its neighborhood with the ring D = 2, is $p_3 = 0.1$
- The probability that the MN is far from home, i.e., outside the ring of D = 2, is $p_4 = 0.1$

Estimation of the update cost

According to this algorithm, update packets are sent at the following times:

• When a MN switches to sleep-mode, it sends a status packet to the SDR to notify it of this status. This packet is propagated to the SDR which places this MN on paging list. It will receive an acknowledgement. That yields a cost of

$$2\alpha(C_w + C_l) \quad (1)$$

• When a MN receives a page, it responds through the serving AR by updating its current location. This occurs at session arrival rate, λ. That yields

$$\lambda(C_w + C_l) \quad (2)$$

• Also when a MN crosses a FPA boundary, it updates the serving SDR. This occurs at the rate of crossing the FPA boundary, which in turn depends on the perimeter of the FPA. The perimeter of a FPA of size D is given by

$$L(D) = (12D + 6)R \quad (3)$$

Where D is the number of concentric rings of cells numbered 0, 1, 2, Figure 2, and R is the radius of each cell.

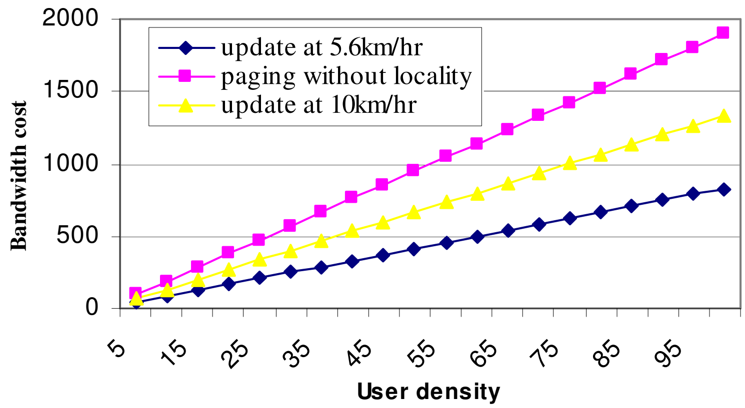

Figure 3. Individual contributions of paging and update without locality probabilities (cell radius 500 m).

Table 1. Parameter values used for computation.

α	λ	R	Cw	Cl	v
0.6	0.42/h	800, 500 m	1	0.5	5.6 km/h, 10 km/h

We use the fluid flow mobility model to estimate the number of MNs that cross the FPA boundary per unit time. This is given by

$$R_c = \frac{\bar{v}L(D)\rho}{\pi} = \Phi\rho \quad (4)$$

Where $\bar{v}$ is the average velocity of the MNs. This means the cost of crossing the boundary is

$$(C_w + C_l)\Phi\rho \quad (5)$$

Putting (1), (2), and (5) together we get total update cost as

$$\begin{aligned} C_u &= 2\alpha(C_w + C_l)\rho + \lambda(C_w + C_l)\rho + (C_w + C_l)\Phi\rho \\ &= [(2\alpha + \lambda + \Phi)(C_w + C_l)]\rho \end{aligned} \quad (6)$$

Estimate of the paging cost

Paging cost depends on the number of cells that are paged before a MN is found. The number of cells within a given ring, D, is 3D(D+1)+1. Thus, the average bandwidth cost of paging a single MN is estimated as:

$$[3D(D+1)+1](C_w + C_l)p \quad (7)$$

Where *p* is location probability. Therefore the total cost of update and paging for MNs due to our algorithm is

$$\begin{aligned} C &= [(2\alpha + \lambda + \Phi)(C_w + C_l)]\rho + [3D(D+1)+1](C_w + C_l)p\rho \\ &= \{[(2\alpha + \lambda + \Phi)(C_w + C_l)] + p[3D(D+1)+1](C_w + C_l)\}\rho \end{aligned} \quad (8)$$

NUMERICAL RESULTS AND DISCUSSION

The algorithm presupposes that the SDR knows the position of the cells in its coverage area and therefore the neighbors that constitute the DPA. We demonstrate the effect of locality probability on the average paging and update costs with the MNs whose home cell is the cell at D = 0 in Figure 2. The parameter values used to estimate the costs is shown in Table 1.

The algorithm is designed for micro cellular systems which are more suitable for urban areas. In micro cells, about 80 ~ 90% of mobile users are pedestrians or vehicles moving at low speeds. We investigate the individual contributions of paging and update to the overall cost. It was discovered that the system bandwidth consumed for paging is much greater than that consumed for update when the locality probabilities were not used. This result is shown in Figure 3. Notice that even at higher average MN speed, which incurs more update cost, the cost of paging without consideration for the locality in mobile behavior is still higher. However, when the locality factor in mobile user behavior was considered, paging cost drastically came down, and contributes much less than the update in the overall cost as shown in Figure 4.

Figure 5 shows the overall cost of paging and update. Observe that the total cost due to paging and update is reduced by over 40% when locality in user movement is considered at a speed of 10 km/h, but at lower speeds such as 5.6/h, when MNs do not cross cell or PA bounda-

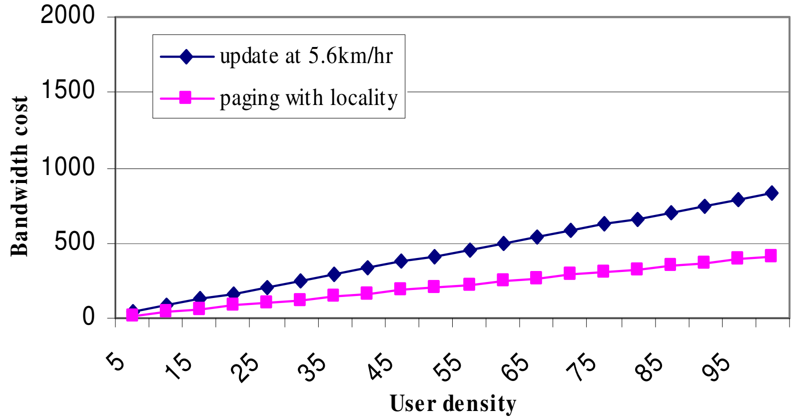

Figure 4. Individual contributions of paging and update costs with locality probability (cell radius 500 m).

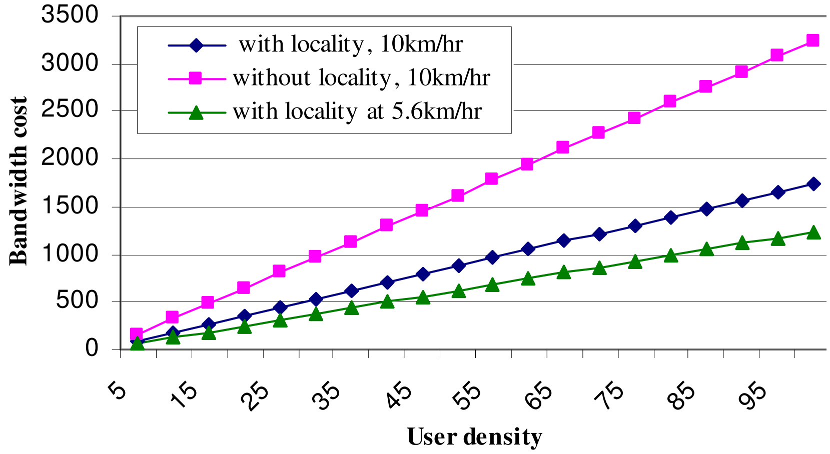

Figure 5. Overall cost of paging and update, with and without locality probability, at 10 km/h and 5.6 km/h (cell radius 500 m).

boundaries so fast, the overall cost is reduced by over 60%. Notice that, unlike other dynamic paging area algorithms that suffer from complexity, this cost reduction is achieved with a simple algorithm that will be easy to implement. Also notice that the cost estimation is for the worst case condition, where all the DPAs will be searched before a MN is found. In places like Africa, where mobile communication is the major means of communication, this algorithm will prove more effective and economical.

It should be noted that this work aimed at demonstrating that consideration of user life-style in designing mobile systems will help to remove unnecessary system cost, which also improves overall performance. The idea presented here has never, to the best of the author's knowledge, been explored in paging cost reduction in mobile communications systems; so, there is room for further improvements. This work has some short comings in the sense that the cost estimation is fairly rough; a better computation method could be evolved to bring out the benefits of the technique even better. Again, a MN resident in the center cell (cell numbered 0 in Figure 2) was used for this cost estimation. When every single cell is considered, the boundary effect, with respect to the FPA, will be taken into consideration.

This is because some cells have neighbors which belong to another FPA (subdomain). This implies that the overall cost in a given FPA will be reduced. This level of computation will give a basis for fair comparison with other methods.

Anticipated difficulty in implementation could arise from the fact that, within a FPA, each MN will be identified with respect to its home cell and its levels of neighbors in order for the paging machine to compute the cells to be

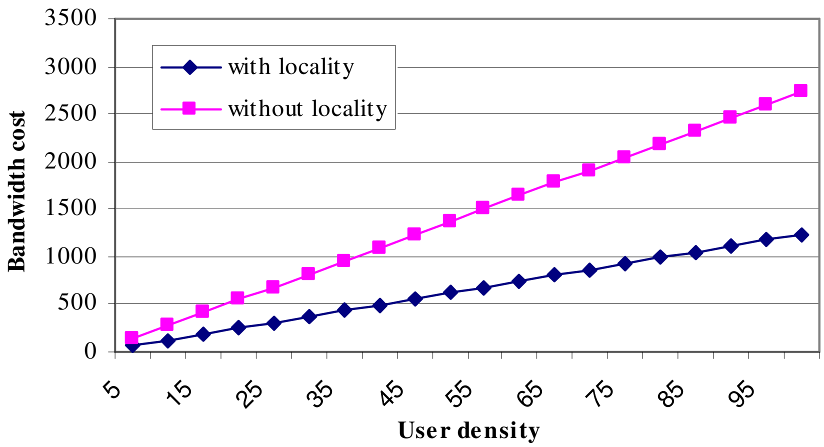

Figure 6. Overall cost of paging and update, with and without locality probability, at 10 km/h and (cell radius 800 m).

paged. This may impact on system memory.

Conclusion

A paging design for a wireless cellular Internet is considered. It was observed that considering user behavioral parameters in the design of mobility management function such as paging helps to obtain a more accurate and less expensive solutions. When the concept of locality in mobile user behavior, which means that users often stay within their home cells or its closest neighborhood, is used in constructing a paging algorithm, 40~60% reduction in paging cost could be achieved. The algorithm is simple and economical, which makes it suitable for African environments where mobile communications is the major means of communications, and where a great majority of the populace is poor. The author observed that using parameters derived from hu-man statistics and behavioral patterns for designing systems that serve human beings is better than using parameters derived from only ordinary mathematical logic. The cost estimation used in this work is fairly rough. There is therefore room for further improvements. This method may also impact on system memory due to individual consideration of MNs. However, in rural areas where MN density is less, this problem is not envisaged.

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