# INTELLIGENT PAGING STRATEGIES FOR PERSONAL COMMUNICATION SERVICES NETWORK

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## Abstract

This paper presents two intelligent paging strategies for a Personal Communication Services Network (PCSN). They are termed as sequential intelligent paging (SIP) and parallel-o-sequential intelligent paging (PSIP). Both are intelligent in the sense that cell(s) to be paged in a cycle are determined from the occupancy probability vector. Unlike the conventional blanket paging where all cells in a location area are polled at a time, in SIP (PSIP) one cell (a group of cells) is polled at a time. We compare the proposed methods with the conventional approach in respect of signaling load, polling cost, and delay. The proposed schemes lead to a decrease in paging signaling load at the cost of some extra processing power. When high intensity traffic is expected, PSIP is always preferred to other paging schemes. However, when incoming traffic rate is low, SIP performs better when paging cost per cycle is the criterion for choosing a particular scheme of paging. When better expected discovery rate per cycle is to be achieved, PSIP scheme should be chosen. The efficacy of these two intelligent paging strategies is shown with the help of simulation results.

The following notations are used in this paper.

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#### **NOTATIONS:**

S = Total number of cells in an LA

 $v_{max}$  = Maximum speed of a mobile terminal (kmhr<sup>-1</sup>)

 $v_{min}$  = Minimum speed of a mobile terminal (kmhr<sup>-1</sup>)

 $\rho$  = Density of MTs (km<sup>-2</sup>)

 $\mu$  = Average number of incoming calls per MT per hour  $\lambda_{pg} = Paging rate$ 

 $\phi$  = call-to-mobility ratio (CMR)A<sub>cell</sub> = Area of a cell

 $K^{conv}$  = granularity factor in conventional paging  $K^{SIP}$  = Granularity factor in sequential paging

 $K^{PSIP}$  = Granularity factor in parallel-o sequential intelligent paging

S<sup>conv</sup>= Number of times an MT is paged in conventional paging before it is found

 $\hat{S}^{SD}$  = Number of times an MT is paged in sequential paging before it is found

S<sup>PSIP</sup> = Number of times an MT is paged in parallel-osequential intelligent paging before it is found

F<sup>conv</sup>= Expected discovery rate of MTs per polling cycle in conventional paging

 $F^{SIP}$  = Expected discovery rate of MTs per polling cycle in sequential paging

 $F^{PSIP}$  = Expected discovery rate of MTs per polling cycle in parallel-o-sequential intelligent paging

<sup>onv</sup> = Paging delay in conventional paging

 $\tau^{SIP}$  = Paging delay in sequential paging

 $\tau^{PSIP}$  = Paging delay in sequential-o-parallel intelligent paging

 $T_p B_p$  = Time bandwidth product for paging messages

 $C_p^{cohv}$  = Paging cost in conventional paging  $C_p^{SIP}$  = Paging cost in sequential paging  $C_p^{PSIP}$  = Paging cost in parallel-o-sequential intelligent paging

P = Occupancy probability vector

p<sub>i</sub>= Probability of finding the MT in the ith cell

 $P_{SFP}$  = Probability of successful first paging

# 1. INTRODUCTION

Recent advances in wireless communication have led to an unprecedented growth of a collection of untethered communication services under the generic name Personal Communication Services (PCS) [2]-[4] that support personal mobility based on personal number, terminal mobility provided by wireless access and service portability through management of user service profiles. Thus, it will lead to ubiquitous availability of services to facilitate the exchange of information between nomadic end users, independent of time, location and access methods. We consider a hierarchical structure of PCS network (PCSN) [3] where the total service area (SA) is divided into a number of location areas (LAs). Each LA is further subdivided into a number of cells. For each cell, there is a base station (BS). The function of a BS is to provide the radio link to the MTs within a cell corresponding to the BS. The BSs within an LA talk with each other through a mobile switching center (MSC). With the advent of third generation mobile telecommunication Universal Personal , systems,

Telecommunication (UPT) [5], Universal Telecommunication systems (UMTs) [6] are now in the offing which enable each UPT user to participate in a user-defined set of subscribed services and to originate and receive calls on the basis of unique personal, network independent UPT number across multiple networks at any terminal, independent geographic location. A more efficient use of wireless resources in emerging PCS requires much smaller cell size (micro cell and pico cells) than those used in conventional cellular networks. Tracking the MTs will become a challenging task as the cell sizes become smaller and the number of cells increases.

One of the main objectives of PCS is to support wide spread roaming by the MTs. GSM is the second generation Pan-European digital cellular standard. GSM has also been chosen to provide PCS in India also partly because international roaming is a key requirement in PCS. Fig. 1 displays the primary GSM functional element [7]. These elements are connected by SS7 links [8] as indicated in Fig. 1 by solid lines without arrows.



Fig. 1 GSM functional elements

The objective of a successful paging is to establish a wireless signaling association between the MT and the network. In Second Generation Mobile Communication Systems (SGMCTs) the issue of finding an MT is treated as follows. The network keeps track of the location of every attached MT with the accuracy of an LA. A location update in the database takes place whenever an attached MT crosses the boundaries of an LA. Whenever an incoming call arrives the network has to locate the called MT within the precision of a cell i.e. to determine the base station via which a wireless signaling link between the MT and the network can be established. During paging, a specific message is broadcast simultaneously via all BSs over the whole LA so as to make alert the called MT i.e., paging area is equal to the LA. The MT, upon receiving the paging request responds to the BS with the stronger received signal strength. Then a wireless link between the called MT and the network is established. This completes process of locating an MT. Since paging amounts to issuing queries about location of the called MTs, these queries require signaling messages. Since the boundaries of the LAs are fixed, MTs moving with high velocities will register more frequently or require larger LAs, which entail higher paging cost. It is also evident that the paging signaling overhead is proportional to the size of the location area in conventional polling [9]. For high call-to-mobility ratio (CMR), the paging cost becomes prohibitively high [9].

With the increase in number of service and number of MTs in service, the radio spectrum will become a scarce commodity. This calls for a reduction in signaling load between MTs and BSs in order to make more bandwidth available for voice, video and data traffic. So a more efficient paging strategy is now necessary. One of the key issues addressed here is to deploy the methods of intelligent paging, which results in consequent reduction in signaling load associated with paging.

The growing demand for PCS and finite available bandwidth motivated several investigations into the methods of delivering calls. A scheme called reverse virtual call setup (RVC) which requires a few new network SS7 signaling messages was proposed in [10]. RVC can function within the existing cellular paging network or with an integrated overlaid paging network. A method that saves paging signaling load by exploiting information related to the MT location during the most recent interaction between the MT and the PCSN was suggested in [11]. The delay time for paging and paging response time were analyzed in [12]. A selective paging scheme for PCSN was proposed by Akyldiz et al. [13] which modeled the movement of MTs as onedimensional and two dimensional hexagonal, mesh random walk. A state based paging technique has been dealt in [14]. While variation of optimum total cost with call-to-mobility ratio has been discussed in [13], LA planning based on time zones and categories of MTs is presented in [11]. Average paging/registration cost rate incurred in greedy registration procedure is compared with a timer-based method in [14]. The aspects like reduction of paging signaling load and increase in expected discovery rate of MTs were not discussed in [10]-[14]. Our paper attempts to fill in this gap.

In this paper, we propose novel, selective paging methods that reduce paging signaling load and improve upon the expected discovery rate of MTs. We apply street unit model [11] and illustrate our method on a simple, time-varying Gaussian user location distribution which often arises as a result of isotropic, brownian motion of MTs [15].

Section I deals with the review of previous works, motivation behind the work and our contribution. Section II describes the methodology. Section III discusses the SIP and section IV deals with PSIP. Simulation results and related discussions have been presented in section V. Section VI sums up the entire work.

#### 2. METHODOLOGY

The movement of MTs is modeled according to some ergodic, stochastic process. In order to evaluate quantitatively, the average cost of paging, time varying probability distributions on MTs are required. These distributions may be derived from the specific motion models, approximated via empirical data or even provided by the MTs in the form of partial itinerary at the time of last contact. In purely sequential polling one cell is polled at a time. Sometimes, instead of polling one cell at a time, we go for polling a cluster of cells in an LA, called parallel-osequential intelligent polling (PSIP) which is a special case of sequential intelligent polling (SIP). At the instance of a call meant for to be terminated to an MT, which roams within a certain LA, paging is initially performed within a portion of LA, which is a subset of the actual LA. This portion of the LA, which is a set of base stations of paging (BSPs), is called a paging area (PA). Intelligent paging is a multi-step paging strategy which aims at determining the proper PA within which the called MT currently roams. The grouping of BSPs into PA may be a) fixed where long term changes are allowed b) semi-dynamic where adjacent BSPs can be grouped into PAs while short term changes are allowed c)fully dynamic where any BSP combination is allowed. The last one offers greater flexibility.

We, now, define granularity factor (K), which shows fineness in polling. In general, we define granularity factor as K = (number of cells to be polled)/(number of cells in an LA).

The maximum value of granularity factor is 1 i.e., when all cells in an LA are polled in one polling cycle. Hence,  $K^{SIP}=1/(number of cells in an LA)$ . As the allowable paging delay is the constraint governing the number of paging steps, sometimes we go for a PSIP the cells where a cluster of cells are polled at a time i.e., granularity factor is  $K^{PSIP}$  where  $1>K^{PSIP}>K^{SIP}$ . The PSIP aims at reducing the paging load within an LA without reducing the LA size and keeping the delay under tolerable limits.

We apply the street unit model [11] where the MTs are assumed to be moving according to some ergodic, stochastic process. The street network has three types of streets namely, i) single lane highway ii) multi lane highway iii) crossing of two single lane streets. The street unit model describes the mobility behavior of MTs within an accuracy of a few meters. A single segment i.e. a street unit is characterized by a)its length b)number of lanes and c)capacity. We also consider the process of movement to be isotropic, Brownian motion with drift. Drift is defined as mean velocity in a given direction and is used to model the directed traffic such as vehicles along a highway.

We specifically assume that i) probability density function on location of MTs is known and considered to Gaussian pdf ii) time elapsed since the last known location and iii) the paging process described here is rapid enough to the rate of motion of MT i.e., MT to be found, does not change its location during the paging process.

In one dimensional version of Brownian motion, an MT moves by one step  $\Delta x$  to the right with some probability, p and to the left with probability q, and stays there with probability (1-p-q) for each time step  $\Delta t$ . Given the MT starts at time t=0 for position x=0, the Gaussian pdf on the location of an MT is

 $P_{X(t)}(x(t)) = (\pi Dt)^{-0.5} e^{-k(x-vt)*(x-vt)/Dt}$ 

where  $v=(p-q)*(\Delta x/\Delta t)$  is the drift velocity and D=2((1p)p+(1-q)q+2pq)  $(\Delta x)^2/\Delta t$  is the diffusion constant, both functions of the relative values of time and space steps. We then derive the occupancy probability vector of current location of MTs. The probability of occupancy will be The SIP strategy, described here, aims at the significant reduction in load of paging signaling on the radio link. In SIP, one cell is polled at a time and the process continues till such time the called MT is found or timeout occurs whichever is earlier. The selection of the cell to be polled sequentially depends on the determination of occupancy probability vector, which is based on the stochastic modeling delineating the movement of the MT. When the paging is unsuccessful during a polling cycle the MT is paged in other cells of the LA sequentially which have not been polled so far. This phase is completed in one or more

obtained by integrating the density function over the segment associated with the location of an MT. The probability of occupancy of MT in different cells is determined. The cell(s) to be polled depends on the probability occupancy vector and the allowable delay.

than one paging step(s). The paging rate represents the average number of paging packets which arrives at a base station during unit time. In conventional or blanket paging, upon arrival of an incoming call, all cells are polled at a time for locating the called MT i.e., each MT is paged S times before the called MT is discovered. Hence, paging rate in a cell becomes  $\lambda_{pg} = \mu\rho S A_{cell}$ .

In SIP scheme, each paging request is sent to that BS where there is maximum probability of finding the called MT.



#### Figure 2: Routing of PRs in SIP scheme

A forward signaling channel is a common signaling channel assigned to any multiplexed stream of paging and channel allocation packets for a BS to MTs. A typical value of an FSC slot is 18.46 ms. Paging rate in a cell per hour becomes a staggeringly high figure of the order of  $10^5$  for  $\rho \sim 100$  km<sup>-2</sup>, A<sub>cell</sub>~1km<sup>2</sup>, S~20 and  $\mu$ ~10 calls hour<sup>-1</sup>.

Following GSM approach, it will be very difficult to accommodate the paging requests in FSCs unless number of paging packets are increased which will lead to a consequent decrease in number of channel allocation packets and thus results in an increase in call blocking probability. Hence in SIP, the PRs are stored in a buffer in MSC and depending on the occupancy probability vector, a particular BS receives the PR for a particular called MT. The paging cost per polling cycle in this scheme is  $C_p^{SIP} = S A_{cell} \rho \mu T_p B_p$ .

#### 3. PARALLEL-O-SEQUENTIAL INTELLIGENT PAGING

The benefit that accrues out of PSIP is the overwhelming reduction in paging cost and signaling load and significant improvement in expected discovery rate of called MTs. From the performance point of view, the quality of service in terms of paging delay should be similar to the GSM like approach and the processing overhead to exploit the paging related information should not be considerable. Although, the method proposed here, requires some additional storage, it does not impose any additional transaction to the network database since the retrieval of paging related information can be performed in conjunction with the retrieval of user profile during the call setup phase. So PSIP allows for defining larger LA. This in turn leads to a reduction in number of location updates. The number of steps in which the paging process should be completed i.e., the MT is to be found, depends on the allowed delay during paging. In the very first phase, the network decides whether the appropriate type of paging i.e. blanket paging (GSM like approach) or multiple step paging. The network then examines whether paging is needed by checking the current status of the MT. An MT can be switched off so as to make it unreachable. This means not only the MT does not want to make or receive any call, but also the network itself cannot detect the current position of the MT. An MT, which has been switched off, may move into a new LA or even into another network operator's area. When switched on again, the MT should inform the network about its status and location. This procedure is called attachment. If it is detached, the paging request (PR) is cancelled. If it is busy, a relation between the MT and the



**Figure 3: Flowchart for PSIP** 

network already exists and therefore paging is not required. If it is free, the network proceeds for paging upon receipt of a PR. The network examines whether the multiple step paging strategy should be applied or not. The decision is based on the allowable paging delay and the current traffic load which when exceed a threshold value, a multiple step intelligent paging is applied. The flowchart of PSIP is given in Figure 3.

The application of PSIP includes the event of paging failures due to unsuccessful predictions of location of called MT. In such cases, multiple steps are required, i.e., the called MT is paged in another portion of the LA. According to the degree of mobility, MTs are classified as i) high mobility and ii) ordinary mobility. Categorization of MTs according to the mobility behavior is given in [11]. Considering the generic street unit model which may be single lane highway, multi-lane highway or crossing of two single lane highway the occupancy probability vectors for MT may be found for low traffic and high traffic condition. Continuous unsuccessful paging attempts may lead to unacceptable network performance in terms of paging delay. To minimize the number of paging steps, the network should guarantee that the P<sub>SFP</sub> is high (typical value for e.g. 90%). The PA should consist of those cells where sum of probabilities of finding the called MT is greater than or equal to the typical value chosen for P<sub>SFP</sub>. The paging cost per polling cycle in PSIP is  $C_p^{PSIP} = K^{PSIP} S A_{cell} \rho \mu T_p B_p$ .

### 4. RESULTS

Simulation results have shown that SIP and PSIP achieve paging signaling load reduction of the order of 60% or higher compared to the blanket polling applied in GSM. The results presented in this section are based on a single lane highway of a street unit model. The length of the road is 50km. And the width is 0.2km. The vehicular traffic moving along the single lane highway has a maximum speed of 70kmhr<sup>-1</sup> and minimum speed of 30kmhr<sup>-1</sup>.

The cells are assumed to be rectangular having a length of 5km and breadth of 0.2km. The occupancy probability vectors for  $\mu = 1$  call hour<sup>-1</sup> and  $\mu = 3$  calls hour<sup>-1</sup> are furnished in Table I and Table II.

#### Table I: Probability occupancy vector

N	<sub>'max</sub> =70km hour",	v <sub>min</sub> =30km	hour'', $\sigma_v =$	12,μ=I	l call	hour
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Cell	1	2	3	4	5	6	7	8	9	10	
no.											
Р	1.6 x	9.4 x	2.54 x	8.92 x	2.51 x	4.94 x	1.16 x	1.95 x	2.75 x	3.18	
	10-4	10-4	10-3	10 <sup>-3</sup>	10 <sup>-2</sup>	10 <sup>-2</sup>	10 <sup>-1</sup>	10-1	10 <sup>-1</sup>	x 10 <sup>-1</sup>	

Table II :	Probability	occupancy vector
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 $v_{max}=70$  km hour<sup>-1</sup>,  $v_{min}=30$  km hour<sup>-1</sup>,  $\sigma_{v}=12$ ,  $\mu=3$  calls hour<sup>-1</sup>

Cell	1	2	3	4	5	6	7	8	9	10
no.										
Р	17.8 x	4.57 x	2.93 x	4.56 x	1.84 x	1.83 x	4.6 x	2.2 x	1.5 x	2.1
	10-4	10 <sup>-2</sup>	10-1	10-1	10-1	10 <sup>-2</sup>	10-4	10-5	10-5	x 10 <sup>-6</sup>

Table I and II show the probability of occupancy in different cells. It is observed for same range of speed i.e.,  $v_{max}$ ,  $v_{min}$  and average speed the probability of occupying particular cell(s) increases with  $\mu$ . Table III shows a comparison between blanket paging and sequential paging for CMR=0.06. In blanket paging all 10 cells in the LA are to be polled before a called MT can be located whereas in sequential paging the cells with greater probability of occupancy are polled until PSFP is 0.9. Thus signaling load is reduced by 70%. If there are 8 paging channels per BS, a maximum of 8 MTs can be found per polling cycle. In sequential paging, for this example, the expected discovery rate becomes 9.116. The decrease in signaling load in SIP over conventional paging is evident from Table IV. For CMR =0.32, 90% reduction in the signaling load during paging can be achieved by this scheme. The percentage increase in expected discovery rate per polling cycle in SIP over conventional one with CMR is depicted in Fig. 5. The expected discovery rate increases with CMR. And the percentage increase is slightly over 120% for CMR=0.32.

Table V shows a comparison of delay, paging cost and expected discovery rate in conventional paging, SIP and PSIP. When rate of incoming call is less, it is observed that the paging delay in sequential paging is more and three or four polling cycles are required before the called MT is found. In PSIP, the  $P_{SFP}$  is ensured to be 0.9 by polling the required number of select cells and the called MT is located with minimum delay. It is also

observed that, similar to conventional polling, a more or less uniform expected discovery rate per polling cycle can be achieved in PSIP. This is more than twice than that of conventional one. The overhead incurred in PSIP is increased paging cost when  $\mu$  is less.

#### Table III: Conventional paging versus SIP

Number of cells per LA	10
Density of MTs	20
CMR	0.06
K <sup>SIP</sup>	0.1
Paging channel per base station	8
S <sup>conv</sup>	10
SSIP	3
F <sup>conv</sup>	8
F <sup>SIP</sup>	9.116
Percentage decrease in signaling	70

Percentage increase in finding	13.95
expected number of MTs	

Table IV: Signaling load vs. CMR in sequential paging

Call-to-mobility ratio	% decrease in signaling load in sequential paging				
0.02	60				
0.06	70				
0.08	70				
0.16	80				
0.32	90				

# CONCLUSION

Two intelligent paging strategies namely SIP and PSIP have been presented in this paper. The reduction in paging signaling load with the increase in CMR is highlighted also. The paging cost per polling cycle, delay associated with the process of SIP and PSIP and expected discovery rates of MTs per cycle have been studied for low and high intensity traffic conditions. We conclude that in scenarios where high intensity traffic is expected PSIP is always preferred to other paging schemes. However, when incoming traffic rate is low, SIP performs better when paging cost per cycle is the criterion for choosing a particular scheme of paging. When better expected discovery rate per cycle is to be achieved, we must go for PSIP. As the paging cost increases monotonically with each unsuccessful polling cycle, the better option is to adopt PSIP. The efficacy of PSIP strategy as far as paging signaling load is concerned, is directly related to the capability of the network to accurately predict the location of the called MT. As both the schemes presented here achieve a significant reduction of the paging signaling load compared to the technique applied in GSM there is room for defining larger LAs which will lead to minimization of location updating signaling load on the network. The penalty paid i.e., additional delay in case of unsuccessful paging and additional storage space required to process the mobility related information.

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Table V: Comparisons of paging cost per polling cycle and expected discovery rate

μ	$\tau^{conv}$	C <sub>p</sub> <sup>conv</sup>	F <sup>conv</sup>	τ <sup>SIP</sup>	C <sub>p</sub> <sup>SIP</sup>	F <sup>SIP</sup>	τ <sup>PSIP</sup>	Cp <sup>SIP</sup>	F <sup>PSIP</sup>
1	1	0.02	8	4	0.002	6.36	1	0.008	19.372
3	1	0.06	8	3	0.002	9.116	1	0.006	18.67
4	1	0.08	8	3	0.002	11.868	1	0.006	19.75
8	1	0.16	8	2	0.002	15.8	1	0.004	19.875
16	1	0.32	8	1	0.002	19.87	1	0.002	19.87



Figure 5: Percentage increase in expected discovery rate per polling cycle in SIP over conventional paging with CMR



Figure 6: Variation of paging cost per cycle with call arrival rate



Figure 7: Variation of expected discovery rate with call arrival rate