Performance Methods for Mobility Management in Cellular Networks

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ABSTRACT: This paper presents performance methods for mobility management in cellular networks. A queueing analysis is first undertaken, in which the system is modelled as an open Jackson Network, consisting of M M/M/1 queues. Given environmental parameters, the corresponding probability matrix is obtained, and hence the traffic matrix equations. From these equations, the traffic load in each cell is evaluated. Secondly, a BONeS DESIGNER simulation model is created and applied to the evaluation of mobility processing load. One case study has been made on Cellular Digital Packet Data (CDPD) Networks. The results from both analysis and simulation are similar. It is important to note that the proposed traffic analysis approach may also be used for evaluating and analysing other signalling traffic in cellular networks.

I. INTRODUCTION

As PCN technologies are deployed there will be a rapid growth in the number of active subscribers and their mobility may extend well beyond the confines of a single network. Thus, mobility management will be much more sophisticated than the strategies used in today's cellular networks, and the associated processing load impact on the infrastructure entities is expected to be heavy, owing to the frequent relocation of mobile users and the growth in the number of mobile users. The effective methods for evaluating their performance, therefore, are very important in the design of high performance mobility management algorithms.

Section II presents a mobility traffic model for cellular networks based on queueing theory. Section III gives an overview of mobility management in CDPD Networks and an application of the proposed analysis model in the evaluation of CDPD mobility processing traffic. BONeS simulation model and performance results are presented in section IV. Conclusions are given in section V.

II. MOBILITY TRAFFIC MODEL

In existing mobile cellular networks, the location strategies commonly proposed are two-level hierarchical strategies, which maintain a system of home and visited databases - Home Location Register (HLR) and Visitor Location Register (VLR) - to keep track of user locations. These strategies, classified as Classical Strategies (CS), can be seen as a memoryless method which considers each event, for example, each user's movement, as if it is isolated from the previous events.

The classical strategy is used - sometimes with some variants - by many existing mobile radio systems such as GSM, IS-41, CDPD, etc. In this method, it is assumed that location updates are realized whenever the user leaves his current location area (group of cells). More precisely, "location tracking is supported by the Location-Updating procedure, which determines the location area in which the MS is operating and updates HLR and VLR accordingly" [1].

Here, an analysis model of Jackson open network, consisting of M M/M/1 queues, are proposed to analyse mobility processing traffic for CS.

This model, shown in Figure 1, treats each location area as a node. System service coverage area consists of these location areas. When a mobile user moves or roams in the service area, it may cross the boundaries between location areas from time to time. These crossings will initiate a series of registration and location updating procedures and therefore generate certain amount of signalling traffic.

In a given period of time, there are three possible movements for mobiles in the system: a. A mobile stays or moves around within the same location serving area; b. A mobile moves across a boundary and gets into a new adjacent location serving area; c.

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A mobile moves out of the system service area or terminates its call session.

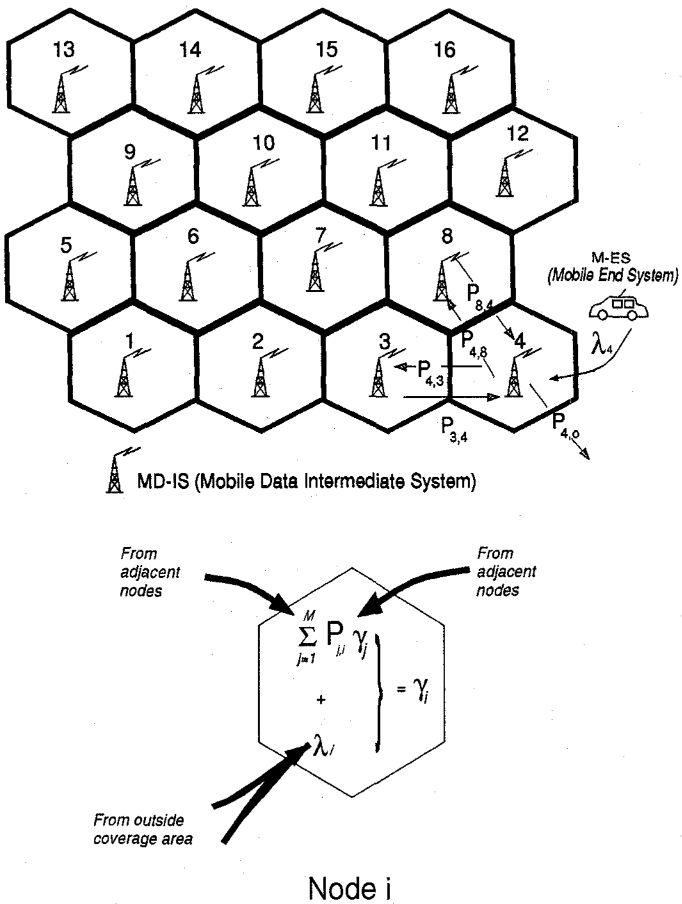

Figure 1. Mobility Traffic Model for CS

Take each location server as a queue, then the whole system can be modelled as a network of queues. Two types of arrivals at each queue can be distinguished: arrivals from the outside of the network and arrivals from other nodes in the network.

Assume that mobiles arrive from outside the coverage area entering node i (queue i) at rate λ_i. After registration at node i (queue i), the M-ES either leaves the system with probability $P_{i,o}$, or goes to cell j with probability $P_{i,j}$. Clearly, we have

$$\sum_{j=1}^{j=M} P_{i,j} = 1 \qquad (1)$$

since each mobile must go somewhere during its session length, or terminate its session. We assume the M-ES terminates its session as it leaves the system. The system as a whole is clearly Markovian [2], with the state being given by the vector of non-negative integers representing the queue lengths at each cell, and posses the properties of Jackson Networks [3].

We may calculate the throughput of each node(queue) using this model.

Let γ_i be the throughput of node i, γ_i must satisfy the traffic equations [3]:

$$\gamma_i = \lambda_i + \sum_{j=1}^{j=M} P_{j,i} * \gamma_j \qquad (2)$$

Since $P_{i,o} \neq 0$ for some i, these equations have a solution.

III. APPLICATION EXAMPLE

As an example, we apply our analysis model to the traffic evaluation of CDPD mobility management. By using same environment parameters as in the simulation described in section IV, we may compare the analysis results with simulation results.

A. CDPD Network System

A CDPD Network is designed to provide wireless packet data connectivity to mobile data communications users by utilizing the available capacity (i.e., unused by voice) on current Advanced Mobile Phone Systems (AMPS). From the mobile subscriber's perspective, the CDPD Network is simply a wireless mobile extension of traditional networks. The primary new components of technology introduced in the CDPD Network are the use of existing cellular channels for air data link services and mobility management [4].

A CDPD network consists of End Systems interconnected to each other by a set of Intermediate System (ISs). End Systems (ESs) are the logical end-points of communications and are, therefore, the source or destination network entities. ESs communicate with each other via ISs. The CDPD Network makes a distinction between Mobile End Systems (M-ESs) and Fixed End Systems (F-ESs) for the purpose of mobility management. ISs implement the network layer relay function as defined by the ISO Reference Model [4]. The Mobile Data Intermediate System (MD-IS) is an IS that controls the mobile data link and manages mobility. It utilizes and controls Mobile Data Base Stations (MDBSs) for transport of data on the air interface.

B. Overview of CDPD mobility management

The distinctive nature of a CDPD network lies primarily in the ability to provide data communication services to mobile users over a wide geographic area, that is, mobility management. The M-ESs may therefore change their subnetwork point of attachment from time to time.

Mobility Management is composed of three processes: Cell Selection, Location Update and Redirection and Forwarding. Cell Selection allows an M-ES to discover, select, and maintain a link on the optimal channel available. When an M-ES decides the current channel no longer provides the required level of service, a new channel is selected from those available. Cell transfer procedures are initiated to notify the network of the change. A distributed location information base is maintained that records the current serving area of each M-ES and is updated as result of the cell transfer procedures. Messages that are destined for M-ESs are directed from an MD-IS in the home area by forwarding to the MD-IS at current serving area. The serving MD-IS completes the delivery by routing to the current cell in which the intended M-ES is located.

The mobility management procedures are concerned with the maintenance of a location information database and routing of NPDUs based on this information. Mobility management is a function located in the three network entities: M-ES, the home MD-IS and the current serving MD-IS.

Each M-ES is aware of its location (i.e., a cell), based on the channel stream it is currently using. When the M-ES moves to another cell, it notifies the network by indicating a switch to the channel stream to be used in the new cell. When registered with the CDPD Network, an M-ES is a member of a current serving area subdomain, that is, it has a serving MD-IS.

MD-ISs perform routing functions based on knowledge of the current location of M-ESs. MD-ISs are the only network-relay systems that have any knowledge of mobility and operate a CDPD-specific Mobile Network Location Protocol (MNLP) to exchange location information.

The MD-IS performs two distinct mobility routing functions: the Mobile Home Function (MHF) and the Mobile Serving Function (MSF). These functions cooperate to provide location-independence.

The MHF of a MD-IS provides two services: Location Directory Service and Redirection and Forwarding Service. The location Directory maintains an information base of the current serving area for each of its homed M-ESs. The MHF operates a packet forwarding service (in the forward direction only). The redirection and forwarding function is based on the principle of encapsulating M-ES addressed packets and forwarding them to MSF in each serving area the M-ES visits.

The MSF of a MD-IS handles the routing of packets for all visiting M-ESs in its serving area. When a M-ES registers for network access in a MD-IS serving area, the MSF notifies the home MD-IS of its current location. The MSF of a MD-IS consists of two services: Registration Directory Service and Re-addressing service. The Registration Directory Service maintains an information base of the M-ESs currently registered in the serving area. The Re-addressing service decapsulates forwarded Network-layer Protocol Data Units (NPDUs) from the MHF and routes them to the correct cell.

C. Mobility Processing Traffic Evaluation

In order to calculate the mobility traffic, we must fix two parameters: a. the number of location serving areas; and b. the average rate at which mobiles come into service coverage area. We use the same figures as in the simulation for these two parameters.

The results for individual nodes based on the traffic equations in section II are shown as plots with those from the simulation in Figure 2.

IV. BONeS SIMULATION MODEL

The model is written using BONeS DESIGNER to simulate the detailed procedures of mobility management in CDPD networks based on CDPD specification and to measure the level of traffic arising from registration and location update activities.

To simplify the simulation, only two major network entities M-ESs and MD-ISs are considered.

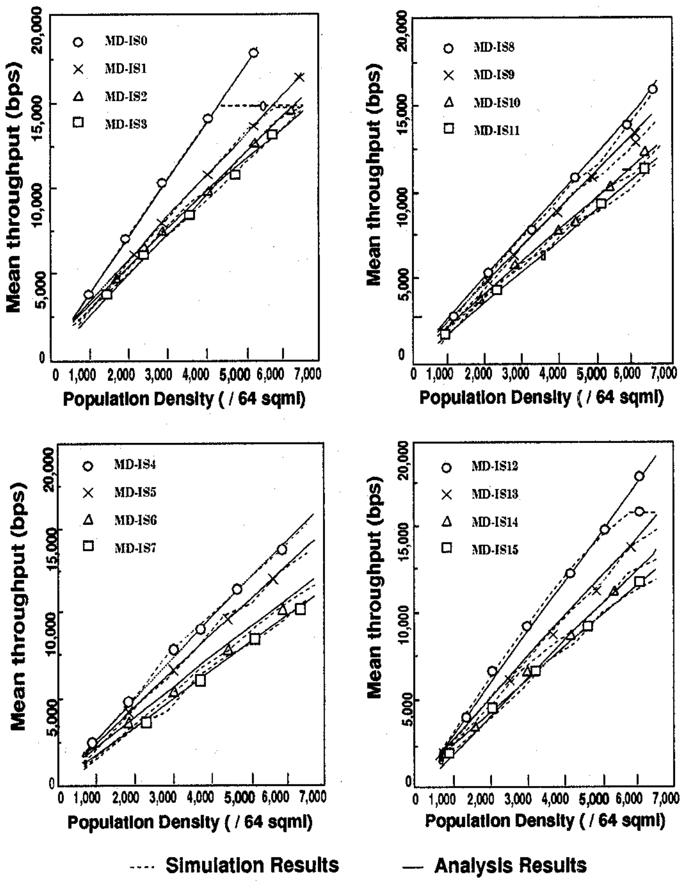

Figure 2. Mobility Traffic for Individual Nodes

MD-ISs provide two mobility routing functions: MHF and MSF. We assume that M-ES arrive from a population of size infinity following a Poisson distribution. Attributes of the user, such as x and y coordinates, speed of motion, direction of motion, and session length are randomly generated from the uniform distributions. These users are supposed to move along a straight line for the duration of their sessions. As M-ES arrives, they are assigned a home MD-IS and registered with it.

According to the procedures described in part B of section III, we can write a simulation model, and the simplified simulation run trace diagram is shown in Figure 3. By setting proper probes in every node, we may collect the mobility processing traffic for each area.

For comparison purpose, we put simulation results and analysis results together, as we have seen in Figure 2. Each block shows mobility processing traffic of four nodes i, ..., i+3 (mod 4). From these plots, we can see that the major trends are similar for both analysis and simulation results, i.e., The mobility processing traffic is getting heavier and heavier as the mobile population density goes up. Due to the session length and channel speed assumptions in simulation, the analysis results slightly overstate those from the simulation.

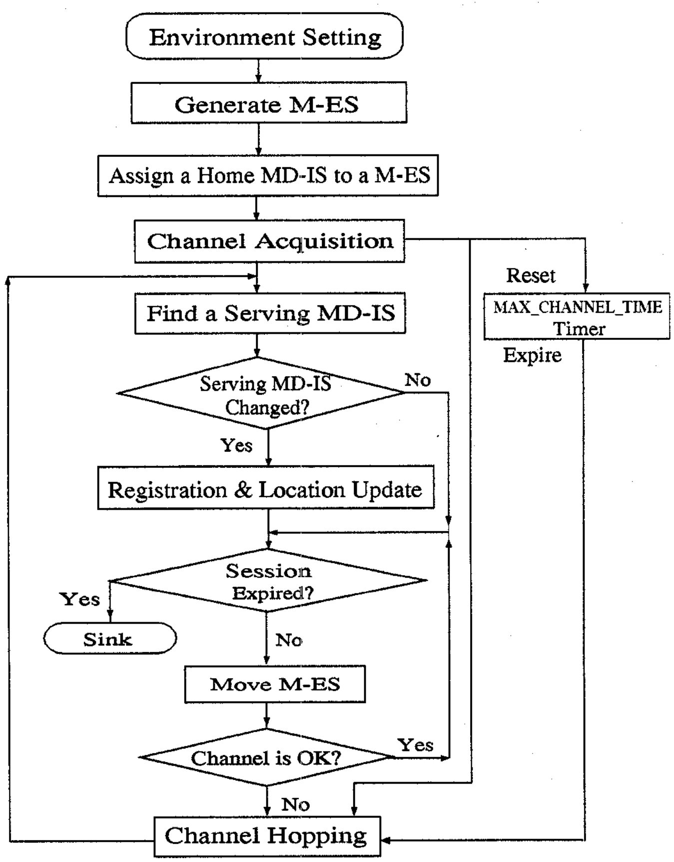

Figure 3. Simulation Run Flowchart

In Figure 4, we plot total control PDUs occupancy and mean delay vs. population density based on the simulation results. As shown from Throughput plot in Figure 4, the traffic arising from control PDUs in the case of low population density is not very high. The control PDUs traffic arises rapidly with the increase of population density, and occupies almost up to full range of the total capacity, therefore, there is not much capacity available for data PDUs exchange.

The similar trend can be seen from delay plot in Figure 4. Under the condition of low population density, the mean delay is stabilized and remains very short, that is, control PDUs can be sent out without much delay. While in the case of high population density, we can see that the mean delay increases quickly and the variance of delay is dramatically large. It indicates that the system is not stable anymore, i.e. control PDUs traffic will significantly influence the performance of the whole system. For normal operation, it is advisable for the system to work within the indicated region in Figure 4.

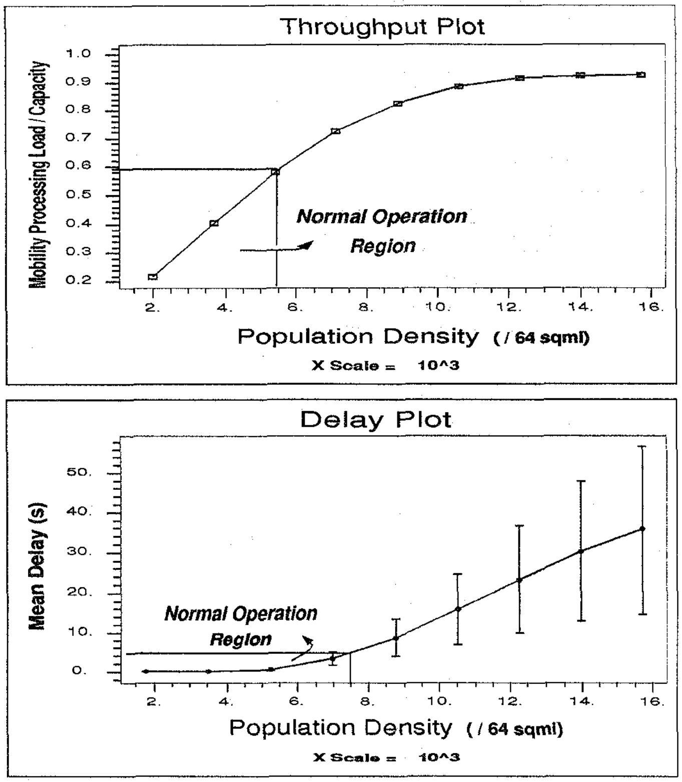

Figure 4. Performance Plots

V. CONLUSIONS

Two methods have been presented to evaluate and analyse the performance of mobility management. A simulation model is written and applied to study the impact of mobility management in CDPD Network. A queueing theory analysis is also undertaken, in which the system is modelled as an open Jackson Network, consisting of M M/M/1 queues. The results from both simulation and analysis are similar and have shown that the mobility processing load may significantly influence the system performance, especially in the cases that mobiles frequently relocate their positions and there are a large number of mobile users in the coverage area. Therefore, we should set safe working parameters, and further studies need to be done to investigate the necessity and possibility of reducing the processing load of mobility management against the future expansion in the population of active mobile users in an optimal way [5].

The more precise results have been obtained based on the BONeS simulation model that is created in order to allow an easy modification of the environment related parameters, thus allowing to directly verify the influence of any modification of the assumed impact values on the overall result.

It is important to note that the proposed traffic analysis approach may also be used for evaluating and analysing other signalling traffic in cellular networks.

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