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Performance Analysis of Energy Consumption of Mobile Station in Three-Tier Network

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Abstract—**Multi-tier network consists of multiple access networks, which are complimentary to each other, from the aspect of mobility support, service coverage area, transmission bandwidth, energy consumption, etc. In previous works on multi-tier network, most of them deal with two access networks. Also the performance of multi-tier location management was analyzed, from the aspect of signaling load or energy consumption. In this paper, we extend previous works on energy consumption of two-tier network by considering three access network. Analytical model for mobility and traffic characteristics of MSs in three-tier network is developed and the performance of location management in three-tier network is analyzed in detail by showing the effect of various parameters on the energy consumption of MSs.**

Index Terms—**Energy Consumption, Three-Tier Network, Performance Analysis**

I. Introduction

Multi-tier network consists of multiple access networks, which are complimentary to each other, from the aspect of mobility support, service coverage area, transmission bandwidth, energy consumption, etc. In multi-tier network a mobile station (MS) has multiple radio interfaces corresponding to multiple access networks. In order to support mobility of an MS in multi-tier network, multi-tier location management has been proposed [1] - [3], where single registration (SR) and multi registration (MR) are proposed. In SR, MSs update the registration area (RA) of only one of available access networks. In MR, on the other hand, MSs update the RAs of all available access networks simultaneously [1] - [3].

In previous works on multi-tier location management, most of them deal with two access networks [1], [2] and the performance of SR and MR was analyzed, from the aspect of signaling load. In [3], although the authors considered three networks, the main focus of their work is to analyze the signaling load of SR and MR, too. Recently, energy consumption of MSs in multi-tier network has been considered as one of the most important issues in multi-tier network since MSs with multiple radio interfaces consume battery power significantly [4] - [6]. In these works [4] - [6], however, the main focus is to reduce energy consumption of MSs by turning off idle WLAN interface as much as possible, and little attention has been paid to mobility management.

In our previous work [7], signaling load and energy consumption in multi-tier network were analyzed in detail. SR and MR were extended to power-efficient SR (PSR) and power-efficient MR (PMR), respectively, by considering energy consumption with SR and MR. Also, efficient power management (EPM) was introduced, where wireless interface of low-tier network is turned off and only turned on when there is an incoming call to the wireless interface. However, only two networks were considered in [7] and works for multiple networks with more than two networks were left as future work, which is not trivial. In this paper, we extend our previous work by considering three networks. Then we develop energy consumption of SR, MR, PSR, PMR, and EPM in three-tier network.

The rest of this paper is organized as follows: Section 2 develops mathematical model of mobility and traffic characteristics of MSs and analyze energy consumption of SR, MR, PSR, PMR, and EPM. Numerical results are presented in Section 3. Finally, conclusions and future works are presented in Section 4.

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II. Performance Analysis

Figure 1 shows a simple logical three-tier network architecture, which consists of low-tier, medium-tier, and high-tier networks with multi-tier home location register (MHLR). High tier network covers the whole service area. Within a high-tier network, medium-tier networks are placed in a non-contiguous way. Likewise, low-tier networks are placed in a non-contiguous way within a medium-tier network. MSs move across the boundary of these networks.

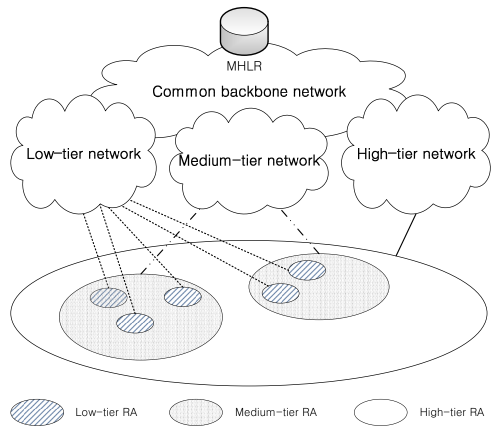

Fig. 1. A simple logical three-tier network architecture.

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For performance analysis, we make the following assumptions for mobility and traffic characteristics of MSs:

- The total number of medium-tier RAs crossed by an MS during the residence time of a high-tier RA is N_{MH}.
- The total number of low-tier RAs crossed by an MS during the residence time of a medium-tier RA is N_{LM}.
- Low tier, medium-tier, and high-tier call arrivals to an MS follow a Poisson arrival with parameters λ_L, λ_M, and λ_H, respectively.
- Call durations of low-tier, medium-tier, and high-tier calls follow an exponential distribution with parameters with μ_L, μ_M, and μ_H, respectively.
- Residence time of low-tier, medium-tier, and high-tier RA follows exponential distribution with parameter μ_l, μ_m, and μ_h, respectively.

To analyze the mobility of MSs, a timing diagram is considered, as shown in Fig. 2, where we assume that an MS moves from left to right and moves across various RAs. In Fig. 2, Hn, Mn, and Ln represent $n-th$ high-tier, medium-tier, and low-tier RAs. T_{ll} and T_{mm} represent the time duration between two consecutive entries of low-tier RA and medium-tier, respectively. T_l represents the residence time of low-tier RA. The stationary time duration between the entry of a high-tier RA and the entry of first medium-tier RA within the high-tier RA, R_{mm}, can be modeled as residual time of the time duration between two consecutive entries of medium-tier RA as follows [8]:

$$f_{R_{mm}}(t) = \frac{1-F_{T_{mm}}(t)}{E[T_{mm}]}. \tag{1}$$

Similarly, the stationary time duration between the exit of a last medium-tier RA and the entry of a new high-tier RA, C_{mm}, can be modeled as elapsed time of the time duration between two consecutive entries of medium-tier RA as follows [8]:

$$f_{C_{mm}}(t) = \frac{1-F_{T_{mm}}(t)}{E[T_{mm}]}. \tag{2}$$

Based on the above equations, the expectations of R_{mm} and C_{mm} are obtained as follows:

$$E[R_{mm}] = E[C_{mm}] = \frac{E[T_{mm}^2]}{2E[T_{mm}]} = \frac{1}{\mu_{mm}}. \tag{3}$$

Similarly, the stationary time duration between the entry of a medium-tier RA and the entry of first low-tier RA within the medium-tier RA, R_{ll}, can be modeled as residual time of the time duration between two consecutive entries of low-tier RA as follows [8]:

$$f_{R_{ll}}(t) = \frac{1-F_{T_{ll}}(t)}{E[T_{ll}]}. \tag{4}$$

Similarly, the stationary time duration between the exit of a last low-tier RA and the exit of medium-tier RA, C_{ll}, can be modeled as elapsed time of the time duration between two consecutive entries of low-tier RA as follows [8]:

$$f_{C_{ll}}(t) = \frac{1-F_{T_{ll}}(t)}{E[T_{ll}]}. \tag{5}$$

Based on the above equations, the expectations of R_{mm} and C_{mm} are obtained as follows:

$$E[R_{ll}] = E[C_{ll}] = \frac{E[T_{ll}^2]}{2E[T_{ll}]} = \frac{1}{\mu_{ll}}. \tag{6}$$

The expected time that low-tier, medium-tier, and high-tier networks are available to an MS is denoted as $E[\theta_H]$ and is obtained as follows:

$$\begin{aligned} E[\theta_H] &= E[R_{mm} + T_{mm}(N_{MH}-1) + C_{mm}] \\ &= \frac{N_{MH}+1}{\mu_{mm}} \end{aligned} \tag{7}$$

The expected time that only medium-tier and high-tier networks are available to an MS is denoted as $E[\theta_M]$ and is obtained as follows:

$$\begin{aligned} E[\theta_M] &= E[(R_{ll} + T_{ll}(N_{LM}-1) + C_{ll})N_{MH}] \\ &= \frac{(N_{LM}+1)N_{MH}}{\mu_{ll}} \end{aligned} \tag{8}$$

The expected time that only high-tier networks are available to an MS is denoted as $E[\theta_L]$ and is obtained as follows:

$$\begin{aligned} E[\theta_L] &= E[T_l N_{LM} N_{MH}] \\ &= \frac{N_{LM}N_{MH}}{\mu_l} \end{aligned} \tag{9}$$

We denote the probability that an MS resides in low-tier, medium-tier, and high-tier RAs is denoted as π_L, π_M, and π_H, respectively, and can be obtained as follows:

$$\pi_L = \frac{E[\theta_L]}{E[\theta_H]+E[\theta_M]+E[\theta_L]} \tag{10}$$

$$\pi_M = \frac{E[\theta_M]}{E[\theta_H]+E[\theta_M]+E[\theta_L]} \tag{11}$$

$$\pi_H = \frac{E[\theta_H]}{E[\theta_H]+E[\theta_M]+E[\theta_L]} \tag{12}$$

Energy consumption of SR is derived as follows:

$$\begin{aligned} E_{SR} &= (\frac{\lambda_H}{\mu_H}+\frac{\lambda_M}{\mu_M}+\frac{\lambda_L}{\mu_L})\pi_H P_{active}^H \\ &+ (1-\frac{\lambda_H}{\mu_H}+\frac{\lambda_M}{\mu_M}+\frac{\lambda_L}{\mu_L})\pi_H)P_{idle}^H \\ &+ (\frac{\lambda_H}{\mu_H}+\frac{\lambda_M}{\mu_M}+\frac{\lambda_L}{\mu_L})\pi_M P_{active}^M \\ &+ (1-\frac{\lambda_H}{\mu_H}+\frac{\lambda_M}{\mu_M}+\frac{\lambda_L}{\mu_L})\pi_M)P_{idle}^M \\ &+ (\frac{\lambda_H}{\mu_H}+\frac{\lambda_M}{\mu_M}+\frac{\lambda_L}{\mu_L})\pi_L P_{active}^L \\ &+ (1-\frac{\lambda_H}{\mu_H}+\frac{\lambda_M}{\mu_M}+\frac{\lambda_L}{\mu_L})\pi_L)P_{idle}^L, \end{aligned} \tag{13}$$

where P_{active}^H, P_{active}^M, and P_{active}^L represent power consumption of an MS of *active* state with high-tier, medium-tier, and low-tier interfaces, respectively. Also, P_{idle}^H, P_{idle}^M, and P_{idle}^L represent power consumption of an MS of *idle* state with high-tier, medium-tier, and low-tier interfaces,

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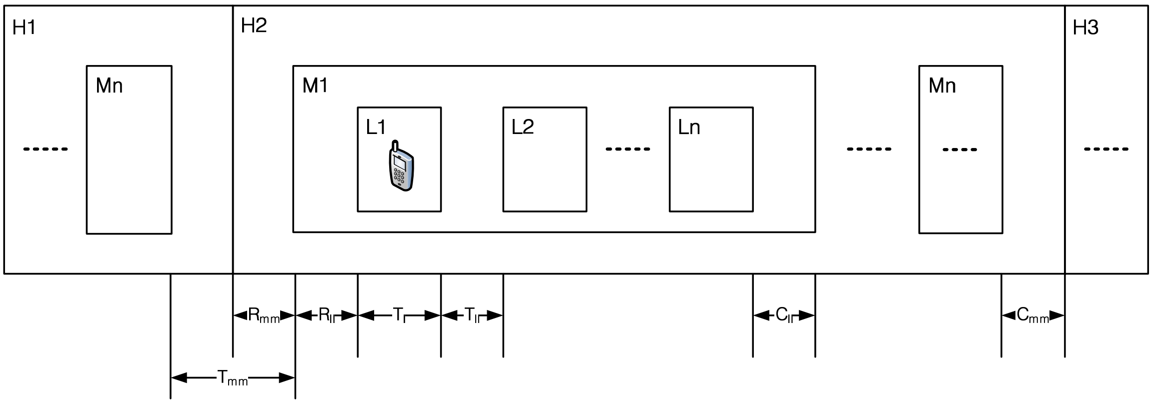

Fig. 2. Timing diagram.

respectively. Energy consumption of PSR, MR, PMR, and EPM are derived as follows:

$$\begin{aligned} E_{PSR} &= (\frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H P^H_{active} \\ &+ (1 - \frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H - \pi_M - \pi_L)P^H_{idle} \\ &+ (\frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_M P^M_{active} \\ &+ (1 - \frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_M - \pi_H - \pi_L)P^M_{idle} \\ &+ (\frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_L P^L_{active} \qquad (14) \\ &+ (1 - \frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_L - \pi_H - \pi_M)P^L_{idle} \end{aligned}$$

$$\begin{aligned} E_{MR} = &((\frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H) + \frac{\lambda_H}{\mu_H}(\pi_M + \pi_L))P^H_{active} \\ &+ (1 - \frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H - \frac{\lambda_H}{\mu_H}(\pi_M + \pi_L)))P^H_{idle} \\ &+ (\frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_M P^M_{active} \\ &+ (1 - (\frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_M)P^M_{idle} \\ &+ \frac{\lambda_L}{\mu_L}\pi_L P^L_{active} + (1 - (\frac{\lambda_L}{\mu_L})\pi_L)P^L_{idle} \qquad (15) \end{aligned}$$

$$\begin{aligned} E_{PMR} = &((\frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H) + \frac{\lambda_H}{\mu_H}(\pi_M + \pi_L))P^H_{active} \\ &+ (1 - \frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H - \frac{\lambda_H}{\mu_H}(\pi_M + \pi_L)))P^H_{idle} \\ &+ (\frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_M P^M_{active} \\ &+ (1 - (\frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_M)\pi_M P^M_{idle} \\ &+ \frac{\lambda_L}{\mu_L}\pi_L P^L_{active} + (1 - (\frac{\lambda_L}{\mu_L}))\pi_L P^L_{idle} \qquad (16) \end{aligned}$$

$$\begin{aligned} E_{EPM} = &((\frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H) + \frac{\lambda_H}{\mu_H}(\pi_M + \pi_L))P^H_{active} \\ &+ (1 - \frac{\lambda_H}{\mu_H} + \frac{\lambda_M}{\mu_M} + \frac{\lambda_L}{\mu_L})\pi_H - \frac{\lambda_H}{\mu_H}(\pi_M + \pi_L)))P^H_{idle} \\ &+ \frac{\lambda_M}{\mu_M}\pi_M P^M_{active} + \frac{\lambda_L}{\mu_L}\pi_M P^L_{active} \qquad (17) \end{aligned}$$

III. Numerical Examples

For numerical examples, default parameter values for mobility and traffic characteristics and power consumption are defined in Tables 1 and 2. Also, $N_{LM} = 10$ and $N_{MH} = 5$ are assumed.

TABLE I
PARAMETER VALUES FOR MOBILITY AND TRAFFIC CHARACTERISTICS.

λ_L	μ_L	λ_M	μ_M	λ_H	μ_H	μ_l	μ_{mm}	μ_{ll}
10	100	6	60	3	30	10	2	10

TABLE II
PARAMETER VALUES FOR POWER CONSUMPTION.

P^H_{active}	P^H_{idle}	P^M_{active}	P^M_{idle}	P^L_{active}	P^L_{idle}
$1.254W$	$0.125W$	$1.4W$	$0.6W$	$1.65W$	$1.15W$

Figures 3, 4, and 5 show energy consumption per unit second for varying the values of low-tier, medium-tier, and high-tier call arrival rates. As shown in Figs. 3, 4, and 5, the energy consumption increases as the call arrival rate increases, since the probability that an MS stays in *active* state increases, although the rate of increases are different in Figs. 3, 4, and 5. SR and MR have the largest energy consumption and EPM has the smallest energy consumption. On the other hand, PSR and PMR have less energy consumption than SR and MR, and have larger energy consumption than EPM. These results are very similar to those of our previous works on two-tier network and thus, the results obtained in Figs. 3, 4, and 5 can be generalized in general multi-tier networks.

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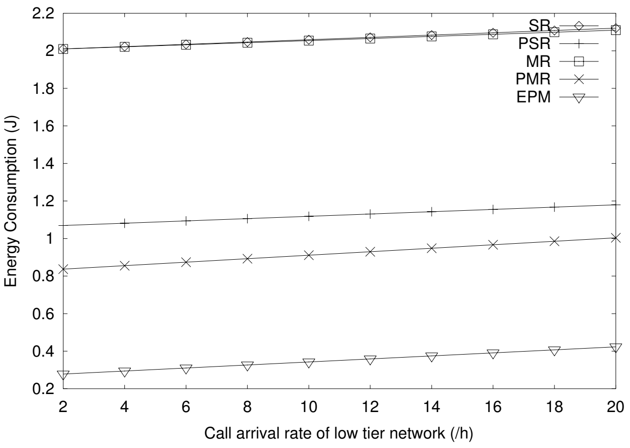

Fig. 3. Energy consumption per unit second for varying the values of low-tier call arrival rate.

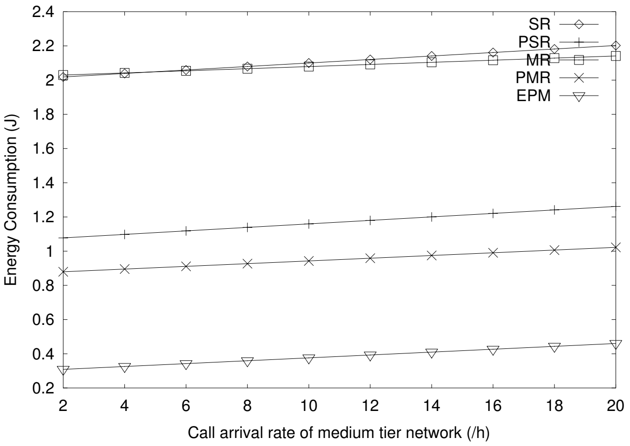

Fig. 4. Energy consumption per unit second for varying the values of medium-tier call arrival rate.

Figure 6 shows energy consumption per unit second for varying the values of mobility of low-tier RA. The relative values of energy consumption are very similar to those in Figs. 3, 4, and 5. However, the result in Fig. 6 shows that energy consumption is irrelevant of mobility of MSs, since mobility of MSs does not change the steady state probability of *active* and *idle* states of MSs.

IV. Conclusions and Future Works

In this paper, we analyze the performance of energy consumption of MSs in three-tier network in detail and show the effect of various parameters on the energy consumption. From the results, it was shown that SR and MR have the largest energy consumption and EPM has the smallest energy consumption. On the other hand, PSR and PMR have less energy consumption than SR and MR, and have larger energy

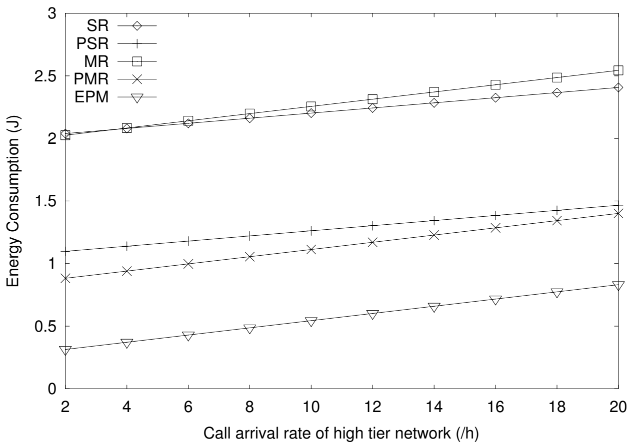

Fig. 5. Energy consumption per unit second for varying the values of high-tier call arrival rate.

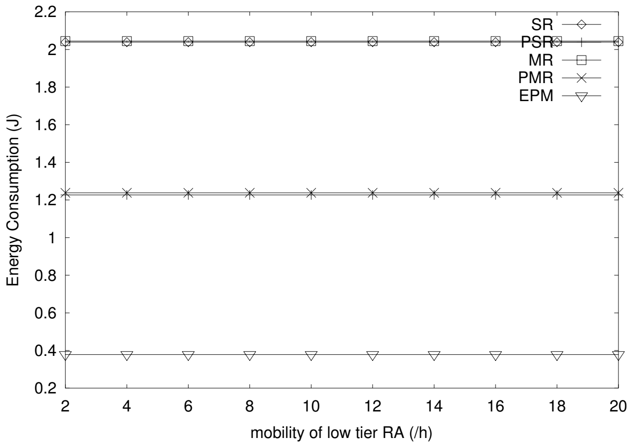

Fig. 6. Energy consumption per unit second for varying the values of mobility of low-tier RA.

consumption than EPM. Also, it was shown that energy consumption is irrelevant of mobility of MSs. In our future works, we will extend the analytical methodology for the performance analysis of energy consumption for MSs in three-tier network to general multi-tier networks with more than three networks based on modeling of mobility and traffic characteristics of MSs.

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