Location Management of SIGMA

Mohammed Atiquzzaman, Abu Ahmed Sayeem Reaz, Shaojian Fu, William Ivancic

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Telecommunication & Network Research Lab

School of Computer Science

THE UNIVERSITY OF OKLAHOMA

200 Felgar Street, Room 160, Norman, Oklahoma 73019-6151
(405)-325-0582, atiq@ou.edu, www.cs.ou.edu/~netlab

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Mohammed Atiquzzaman, Abu S. Reaz, Shaojian Fu
Telecommunications and Networks Research Lab
School of Computer Science, University of Oklahoma
Norman, OK 73019-6151.
{atiq,sayeem_reaz,sfu}@ou.edu

William Ivancic
Satellite Networks & Architectures Branch
NASA Glenn Research Center
21000 Brookpark Rd. MS 54-8
Cleveland, OH 44135.

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Abstract— **Domain Name System (DNS) can be used as a Location Manager (LM) for mobility management in data networks. The suitability of DNS as a LM can be measured by its success in locating a mobile host. In this paper, we developed an analytical model to measure the performance of DNS as a LM for mobility management in SIGMA, an IP diversity based transport layer mobility management scheme. The model takes into account the radius of the subnet, the residence time of MH in a subnet, network latency and the overlapping distance between two neighboring subnets. Our analysis shows that for a reasonable overlapping distance, DNS can serve as a LM with very high success rate even under high network latency.**

I. INTRODUCTION

Mobile IP (MIP) [1] is a network layer based mobility management scheme for data networks. To solve a number of deficiencies of MIP, such as high handover latency [2], high packet loss rate, inefficient routing, conflict with security solutions [3] and change of Internet infrastructure, a new transport layer based scheme for mobility management, called Seamless IP diversity based Generalized Mobility Architecture (SIGMA) [4], has been developed by researchers at The University of Oklahoma. SIGMA is based on exploiting IP diversity to support seamless handoff resulting in negligible packet delay and loss. It has the advantage of requiring no change in the network infrastructure, ease of interoperability with Internet security solutions, and scalability. Like all mobility management solution, SIGMA requires a Location Manager (LM) to enable Correspondent Nodes (CN) to locate the Mobile Host (MH) as it changes its point of attachment to the network while moving between subnets.

In a regular data network, location is synonymous to the current point of attachment. The point of attachment is represented by the present IP address of the MH. Location management in the mobile environment is more cumbersome as a MH continuously changes its point of attachment hence changing its IP address. Basic functionality of a LM encompasses two operations: *Location Update* which represents updating the LM whenever the location or the IP address of the MH changes and *Location Query* which consists of querying the LM to find the current location of the MH whenever the CN is trying to initiate a communication with the MH [5].

There are two most common choices for implementing a LM:

1) Dedicated Location Manager: A dedicated location manager is deployed specifically to perform location management. The benefit of this system is it can borrow concepts from existing cellular telephone networks to perform the task. However, a significant change in the global Internet infrastructure is required, giving rise to deployment issues.
2) Domain Name System (DNS): The currently deployed DNS [6] in the Internet provides name to IP mapping, and almost all connection establishments starts with a name lookup using DNS. It is, therefore, possible for DNS to serve as a LM and perform the basic operations required to locate an MH. As DNS supports dynamic secure updates [7] and is already part of the existing Internet, the real benefit of this scheme is that no change in the Internet infrastructure is required.

The advantages of being able to deploy DNS as a LM without any change in the Internet infrastructure led us to investigate its suitability as a location manager for transport layer mobility schemes, such as SIGMA, as illustrated in Fig. 1. One of earliest suggestions on using directory server for location management can be found in [8]. It suggests a graph theoretic regional matching to provide locality preserving representations for arbitrary networks. However, it does not provide any specific and real life implementation. Although two more recent proposals outline how DNS can be used for location management [9], [10], it does not deal with the challenges involved in using DNS as a LM, and lacks any results on performance evaluation.

Implementation of DNS as a LM gives rise to many challenges, such as high traffic load, query failure, and unsuccessful update due to packet loss. One of the most significant

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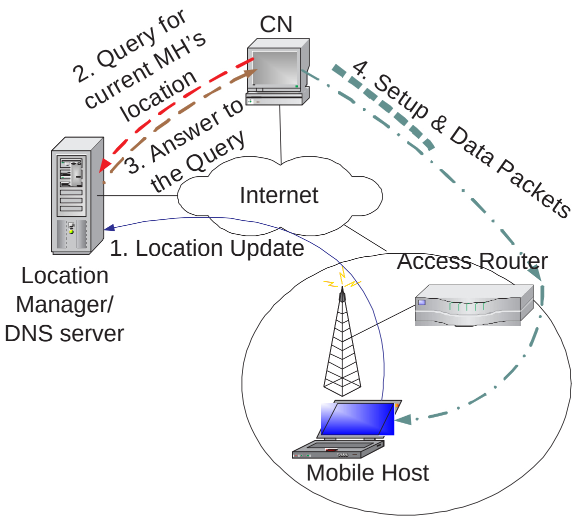

Fig. 1. DNS as Location Manager.

challenges is determining its success in performing location management, measured by the fraction of queries that result in a successful connection to the MH. The *authors are not aware* of any (including [8]–[10]) previous study on a comprehensive study of challenges and performance in using DNS as a LM in mobile data networks. The *objective* of this paper is to analyze the performance of DNS as a LM based on success rate which takes into account the overlapping distance of two neighboring subnets, latency in the network, radius of the subnet and the residence time of MH in that subnet. Our *contributions* in this paper are (i) identifying the issues related to the deployment of DNS as LM, and (ii) developing an analytical model to study the performance of DNS as LM.

The rest of the paper is organized as follows. Sec. II depicts the fundamentals of `SIGMA`, Sec. III describes the deployment of DNS as a LM for `SIGMA`, and Sec. IV describes the issues related to the deployment of DNS as LM. The analytical model for performance evaluation of DNS as a LM is developed in Sec. V. The results on performance of DNS as LM is shown in Sec. VI, followed by conclusions in Sec. VII.

II. BASICS OF `SIGMA`

Seamless IP diversity based Generalized Mobility Architecture (`SIGMA`) [4], [11]–[16] is a new handoff management technique, based on exploiting IP diversity offered by multiple interfaces which is becoming increasingly common for mobile devices. When an MH moves into the coverage of a new subnet, it obtains a new IP address while retaining the old one in the overlapping area of the two subnets. The MH communicates through the old IP address while setting up a new connection through the newly acquired IP address. When the signal strength of the old Access Point (AP) drops below a certain threshold, the connection is handed over to the new subnet and the new IP address is set to be the primary one. When the MH leaves the overlapping area, it releases the old IP address and only communicates over the new IP address. The duration of the MH in the overlapping area and the time during which the MH communicates over both IP addresses depend on the velocity of the MH and the power of the signals from the access points. Each time the MH handsoff to a new subnet, it updates the DNS with its new IP address.

A DNS record can contain two IP addresses corresponding to a host name [6], [17]. The order of storing the addresses determines the priority of the addresses, i.e. the sequence in which the IP addresses will be used by the CN to establish connection with the MH.

III. DNS AND LOCATION MANAGEMENT IN `SIGMA`

Domain Name System is a distributed service that maps host names to corresponding IP addresses and vise versa [6]. All Internet Service Providers (ISP) maintain a Local Name Server (LNS) that *caches* recent name to IP mapping that are processed though the ISPs. Any subsequent request for that name is served directly from the LNS. If the LNS does not have an entry for the name, it contacts the root name server that provides the address of the Authoritative Name Server (ANS) for that domain. Under one domain, there might be several sub-domains in a hierarchy, each of which would have an ANS. Each of the ANS can provide the address of the appropriate sub-domain. The name and address mapping is finally sent back to LNS where it is cached for a certain period of time (called Time To Live (TTL)) as indicated by the corresponding ANS [6].

A. Deployment of DNS as LM

Location management in a mobile environment refers to locating (finding the current IP address) the MH by a CN in order to setup a connection. Most of the connection setups generated in the Internet begin with a name lookup via the DNS [18], i.e. domain name is used as the identity of target host. This affirms the notion of considering DNS as a location manager. Whenever an MH changes its point of attachment, it registers the new IP address with the Authoritative Name Server via dynamic secure update [7]. As DNS is invariant and almost ubiquitous connection originator, all subsequent queries to the DNS for the MH will be served with the new IP address, reflecting the new location of the MH.

In a mobile data network, where the MH frequently changes its point of attachment resulting in frequent updating of the DNS, it is important that all new connection setups query the ANS for the most recent location of the MH, instead of using cached DNS records at the ISP's DNS server. This is required to avoid the CN using obsolete IP address of the MH. Caching at the LNS can be avoided by the ANS assigning a TTL value of *zero*. As a result, all queries will be satisfied from the ANS, which has the most updated IP address of the MH.

One of the location management's most crucial part is when LM tries to identify an MH in its relatively newer point of attachment after a handoff. Any location query before updating the LM might result in an incorrect IP address. Sec IV illustrates the problem in detail. The IP Diversity exploited by `SIGMA` enables the MH to have two IP addresses in the LM during the handover period.

B. *DNS as LM in* SIGMA

Fig. 2 shows the sequence of updates to the ANS by the MH. When the MH reaches the boundary of the overlapping area of the two subnets, it obtains a new IP address and sends an update message to the ANS that stores the new address along with the old one in the DNS, with higher priority being assigned to the old IP address (time t_1). Later on, when the MH hands off based on relative signal qualities of the two access points, it sends another update message, with the new IP address as the first address followed by the old IP address (time t_2). When the MH leaves the overlapping area, it sends an update to the ANS to remove the old IP address (time t_3). In the overlapping area (between t_1 and t_3), ANS responds to location queries with two IP addresses, the sequence being determined by the position of the MH in the overlapping area as shown in Fig. 2.

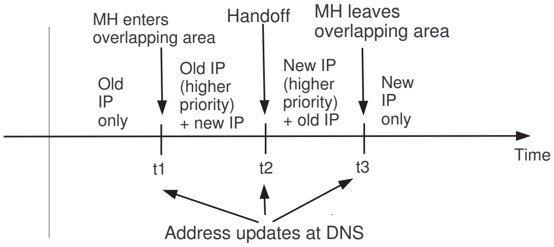

Fig. 2. DNS updates during handoff with IP Diversity.

IV. ISSUES WITH DNS AS LM

Although the use of DNS as a LM for mobility management appears to be promising, in this paper, we investigate the following issues that have to be addressed before it can be deployed in the Internet.

1) **Signalling Load:** The *no-caching* policy implemented by TTL=0 (Sec. III-A) will result in higher DNS query traffic. A DNS query consists of querying the root server and LNSs to find the ANS, followed by the actual query to the ANS for the name to IP address translation. Name Server records are cached for several hours by default. As a result, all queries will not go through the hierarchy of the DNS servers, but rather go to the ANS directly. Every query will, however, pass through the ANS and result in additional traffic. However, it should be noted that about 80% of the queries are processed without referrals to the root name servers and about 60% of them are replied in less than 100 ms [19]. The latency due to the location lookup is thus, not very significant. With today's hardware advancement, we expect the ANS to be able to handle the extra traffic as the web servers handle an even higher volume of traffic.
2) **Compliance with Standards:** Many local name servers do not follow the suggested TTL; rather they use a default minimum value for caching period [20]. In such cases, the IP address obtained from the DNS would be void if a handoff occurred. This is a policy decision, and *to solve this issue,* the LNSs should follow the TTL suggested by the corresponding ANS in order to support mobility.
3) **Loss of DNS Update Message:** Another significant issue related to deployment of DNS as a LM is the possibility of packet loss of the DNS update message. As the DNS update packets are UDP packet, it is just a best effort service and there is a possibility of packet loss. In this case, the update might not take place and the location of the MH would be lost. Dynamic Updates [7] in conjunction with retransmission of lost update packets can be used to address the problem. It allows a device to dynamically update its name-to-IP mapping at the DNS. It supports acknowledgement to ensure successful update of the IP address, thus assuring reliable update.
4) **Out of Date Address:** The most significant issue is during the handoff period. As shown in Fig. 3, when the DNS server is updated (due to handoff) at t'_2 just after the CN has completed a query at t'_1, the address obtained by CN may no longer be valid. The CN may not be able to find the MH when it sends a connection request at t'_3.

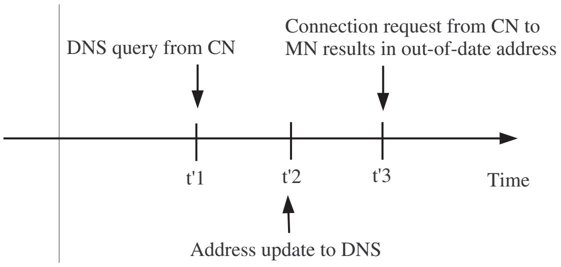

Fig. 3. Effect of obtaining out-of-date address by the CN.

The effect of the above issue is minimized in the our case as we propose the use of the notion of IP diversity and stores multiple addresses in the DNS during the overlapping area (time t_1 to t_3 in Fig. 2). So, location query failure would occur for SIGMA only if the time taken by the name lookup query response to CN from DNS and connection request from CN to MH is more than the residence time of the MH in the overlapping area.

V. ANALYTICAL MODEL FOR PERFORMANCE EVALUATION

Based on the issues described in Sec. IV, we can say that the success of DNS as LM can be determined by the fraction of time it can serve name lookup requests without query failure. Thus the primary success measure of a DNS as LM is determined by how successfully it can provide the CN with the correct address such that the connection establishment request can be sent to the current address of the MH. We define success rate as the fraction of queries successfully served out of the total number of queries. In Sec. V-A, we derive the residence time of an MH in a subnet, in Sec. V-B, we derive the critical time during which location queries carries a possibility of failure, and in Sec. V-C we compute success rate based on traffic arrival rate to LM during its residence time and critical time.

A. Calculation of Residence Time

We assume that a mobile host moves according to the Random Waypoint model [21], which is the most frequently used model in mobile networking research. In this model, an MH randomly selects a destination point in the topology area according to a uniform distribution, then moves towards this point at a random speed, uniformly selected between (v_{min}, v_{max}). One such movement is called an *epoch*, and the elapsed time and the moved distance during an epoch are called *epoch time* and *epoch length*, respectively. At destination point, the MH stays stationary for a period of time, called *pause time*, followed by the start of a new epoch. Let,

$E(T)$ = expected value of *epoch time*.
$E(P)$ = expected value of MH pause time.
$E(L)$ = expected value of *epoch length*.
$E(C)$ = expected number of subnet crossings per *epoch*.
v = moving speed of MH.

The objective of this section is to find the average residence time (T_{sub}^{res}) for an MH in a subnet. It will help us determining the frequency at which an MH changes its point of attachment, and therefore, the frequency of updating the LM. T_{sub}^{res} can be estimated by the time between two successive movements (*epoch time* plus *pause time*) divided by the number of subnet crossings during this epoch, as shown in Eqn. (1):

$$T_{res}^{sub} = \frac{E(T)+E(P)}{E(C)} \tag{1}$$

We first compute $E(T)$. Since *epoch length* and movement speed are independent:

$$E(T) = E(L/v) = E(L)E(1/v) \tag{2}$$

Since the moving speed is of uniform distribution between (v_{min}, v_{max}), we have:

$$\begin{aligned} E(1/v) &= \int_{v_{min}}^{v_{max}} (1/v)\frac{1}{v_{max}-v_{min}}dv \\ &= \frac{\ln(v_{max}/v_{min})}{v_{max}-v_{min}} \end{aligned} \tag{3}$$

where, v_{min} and v_{max} are minimum and maximum values of v.

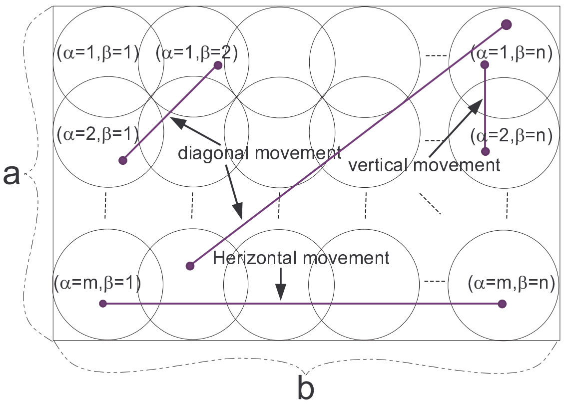

Fig. 4. Arrangement of subnets in a rectangular topology.

In order to determine $E(L)$ and $E(C)$, we assume an arrangement of circular subnets in a rectangular topology as shown in Fig. 4, where m and n are the number of vertically and horizontally arranged subnets in the topology, respectively. From [21], we know that $E(L)$ for a rectangular area of size $a \times b$ can be estimated as:

$$\begin{aligned} E(L) &= \frac{1}{15}\left[\frac{a^3}{b^2}+\frac{b^3}{a^2}+\sqrt{a^2+b^2}\left(3-\frac{a^2}{b^2}-\frac{b^2}{a^2}\right)\right] \\ &+ \frac{1}{6}\left[\frac{b^2}{a}\Phi\left(\frac{\sqrt{a^2+b^2}}{b}\right)+\frac{a^2}{b}\Phi\left(\frac{\sqrt{a^2+b^2}}{a}\right)\right] \\ &\text{where} \quad \Phi(\cdot) = \ln\left(\cdot + \sqrt{(\cdot)^2-1}\right). \end{aligned} \tag{4}$$

Now we can get $E(T)$ by combining Eqns. (2), (3) and (5). For a uniformly distributed pause time between (0, P_{max}), we have:

$$E(P) = \int_0^{P_{max}} \frac{P}{P_{max}}dP = P_{max}/2 \tag{5}$$

Next, we need to find $E(C)$, the general form of which can be expressed as [21]:

$$E(C) = \frac{1}{m^2n^2}\sum_{\alpha_j=1}^{m}\sum_{\beta_j=1}^{n}\sum_{\alpha_i=1}^{m}\sum_{\beta_i=1}^{n} C\left(\begin{array}{c}(\alpha_i,\beta_i)\\(\alpha_j,\beta_j)\end{array}\right) \tag{6}$$

$C\left(\begin{array}{c}(\alpha_i,\beta_i)\\(\alpha_j,\beta_j)\end{array}\right)$ is the number of subnet crossings caused by one movement between subnet (α_i, β_i) to (α_j, β_j), which depends on the actual subnet shape and arrangement. Consider the circular subnet arrangement as shown in Fig. 4, we can observe three kind of movements: horizontal, vertical and diagonal. $C\left(\begin{array}{c}(\alpha_i,\beta_i)\\(\alpha_j,\beta_j)\end{array}\right)$ can be generalized by the following Manhattan distance metric:

$$C\left(\begin{array}{c}(\alpha_i,\beta_i)\\(\alpha_j,\beta_j)\end{array}\right) = |\alpha_i-\alpha_j|+|\beta_i-\beta_j| \tag{7}$$

By substituting Eqn. (7) into Eqn. (6), we can get the expression for $E(C)$:

$$E(C) = \frac{1}{m^2n^2}\sum_{\alpha_j=1}^{m}\sum_{\beta_j=1}^{n}\sum_{\alpha_i=1}^{m}\sum_{\beta_i=1}^{n}\left(|\alpha_i-\alpha_j|+|\beta_i-\beta_j|\right) \tag{8}$$

Substituting Eqns. (2), (5) and (8) into Eqn. (1), we can get the expression for T_{sub}^{res}.

B. Calculation of Critical Time

For analytical tractability, we make the simplifying assumption that all queries are processed at the ANS without any referrals. Then the process of communication initiation between an MH and a CN has two parts. First the CN gets the name-to-IP address mapping from the ANS, followed by initiating a connection with the MH with the IP, as illustrated by the timeline in Fig. 5.

We denote $\Delta t_{1+2} = t_5 - t_4$ and $\Delta t_{2+1} = t_6 - t_5$ as illustrated in Fig. 2. Here Δt_{1+2} is the time during which an MH is in the overlapping area when the first address has a higher priority, i.e. before the handoff, and Δt_{2+1} is the time

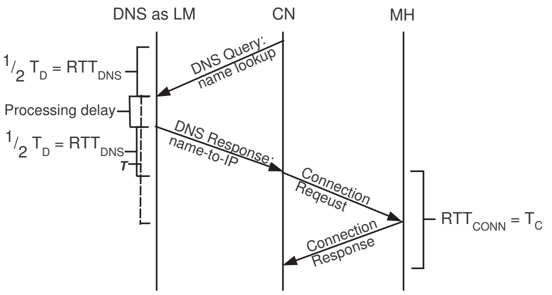

Fig. 5. Timeline of connection initiation from CN to MH.

spent by the MH in overlapping area when the new address has a higher priority, i.e. after the handoff. Let

$$\tau = \left(\frac{1}{2}T_D\right) + \left(\frac{1}{2}T_C\right) + T_S^d \tag{9}$$

Here $\frac{1}{2}T_D$ represents the time taken by the DNS name lookup reply to come from ANS to CN, $\frac{1}{2}T_C$ represents the time taken by the connection establishment request from CN to MH and, T_S^d is the query processing delay at ANS.

If the residency time of an MH in the overlapping area is $\Delta t_{1+2} + \Delta t_{2+1}$, for a DNS query to be successfully served with the current IP address of MH

$$\tau \leq (\Delta t_{1+2} + \Delta t_{2+1}) \tag{10}$$

The round trip delay is sum of round trip propagation delay, transmission delay and queuing delay. If

T_{CA}^d = Propagation delay between CN and ANS
T_{CM}^d = Propagation delay between CN and MH
β_{CA} = BW of the link between CN and ANS
β_{CM} = BW of the link between CN and MH
ψ_D = Avg. DNS query packet size
ψ_C = Avg. connection request packet size
$\overline{\xi}$ = Avg. queuing delay in the network

we have, $\frac{1}{2}T_D = T_{CA}^d + \frac{\psi_D}{\beta_{CA}} + \overline{\xi}$ and $\frac{1}{2}T_C = T_{CM}^d + \frac{\psi_C}{\beta_{CM}} + \overline{\xi}$. Therefore,

$$\tau = T_{CA}^d + T_{CM}^d + \frac{\psi_D}{\beta_{CA}} + \frac{\psi_C}{\beta_{CM}} + 2\overline{\xi} + T_S^d \tag{11}$$

If the network latency increases, τ would increase and result in violation of Eqn. (10). If $\tau > (\Delta t_{1+2} + \Delta t_{2+1})$,

$$T_{cr} = (\tau - (\Delta t_{1+2} + \Delta t_{2+1})) \tag{12}$$

where, any location query made within time T_{cr} would carry a possibility of failure. We call this period *Critical Time*.

If d_{sub} is the radius of a subnet and d_{ovr} is the overlapping distance between adjacent subnets, the asymptotic density function that gives the probability of the MH to be at a certain point on a line segment [0, d_{sub}] is given by $f_x(x) = -\frac{6}{{d_{sub}}^3}x^2 + \frac{6}{{d_{sub}}^2}x$ where x is any point on the line segment reflecting the distance of the MH from the center of the subnet [22]. Thus, probability of an MH being within that subnet is $\int_0^{d_{sub}} f_x(x)dx = 1$, and probability of the MH being in the overlapping area is $\int_{x_{min}}^{d_{sub}} f_x(x)dx = 1 + 2\left(\frac{x_{min}}{d_{sub}}\right)^3 - 3\left(\frac{x_{min}}{d_{sub}}\right)^2$ where $x_{min} = d_{sub} - d_{ovr}$. If T_{ovr}^{res} is the residence time of MH in the overlapping area, $T_{ovr}^{res} = T_{sub}^{res}\int_{x_{min}}^{d_{sub}} f_x(x)dx$.

From Eqn. (9), we can get

$$T_{ovr}^{res} = (\Delta t_{1+2} + \Delta t_{2+1}) = T_{sub}^{res}\int_{x_{min}}^{d_{sub}} f_x(x)dx \tag{13}$$

Values obtained from Eqns. (11) and (13) can be used in Eqn. (12) to get T_{cr}.

C. Calculation of Success Rate

We now determine the number of failures during a single handoff as E[$\chi(T_{cr})$] and total number of queries as $E[\chi(T_{sub}^{res})]$ where $\chi(t)$ represents number of queries within time t. If λ is the arrival rate of name lookup query to the LM, we have $E[\chi(T_{cr})] = \lambda T_{cr}$ and $E[\chi(T_{sub}^{res})] = \lambda T_{sub}^{res}$.

The success of DNS as a LM, depends on the fraction of time it can successfully serve the right IP address out of all the queries. So, Success Rate, ρ, can be defined as

$$\rho = \frac{E[\chi(T_{cov}^{res})] - E[\chi(T_{cr})]}{E[\chi(T_{cov}^{res})]} \tag{14}$$

Values obtained from Eqns. (1) and (13) are used to evaluate Eqn. (14).

VI. RESULTS

The success rate of DNS as LM depends on residence time of MH in a subnet and the critical time (Eqn. (14)). Critical time is dependant on the network latency and the residence time of MH in the overlapping area. Network latency depends on propagation, transmission and queueing delays at the network (Eqn. (11)). Overlapping distance and residence time gives the time during which an MH stays in the overlapping area. In short, the success rate depends on network latency, residence time, and overlapping distance for a given subnet.

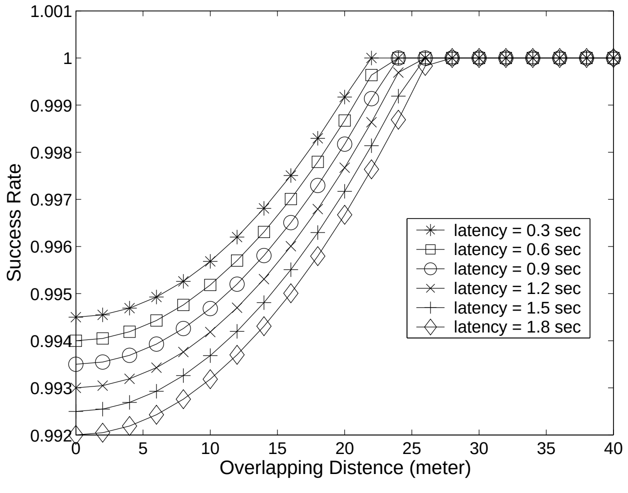

Fig. 6. Success rate against overlapping area for different network latency.

The variation of the success rate over different overlapping distances is one of the performance measures. As the overlapping distance, d_{ovr}, increases, the possibility of locating the MH even with the old IP address increases. On the other hand, if the network latency and the processing delay at server, τ, are very low, the probability of query failure is also very low.

Fig. 6 shows the success rate as a function of overlapping distances for T_{sub}^{res} = 300 sec, T_S^d = 3 sec, and d_{sub} = 500 meter. For network latencies between 0.3 to 1.8 seconds and overlapping distance of about 30 meters (or above) , we can see that the success rate remains at one.

For a fixed network latency of 0.5 sec, and varying T_S^d from 2 to 3.25 sec, we see from Fig. 7 that for an overlapping distance greater than 25 meters, the success rate settles to one even with a high T_S^d value of 3.25 sec.

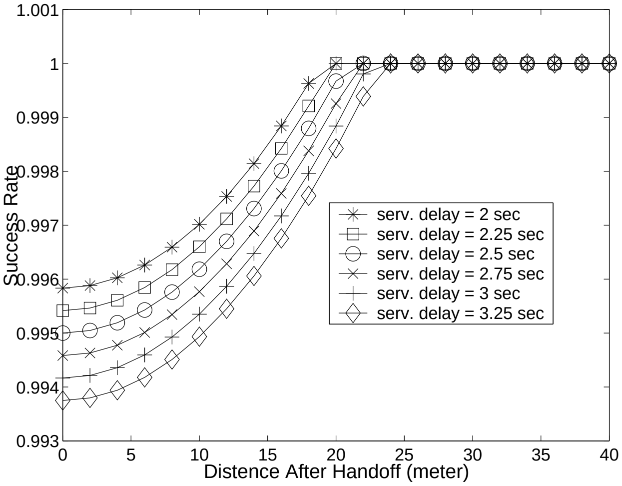

Fig. 7. Success rate against overlapping area for different query processing time at server.

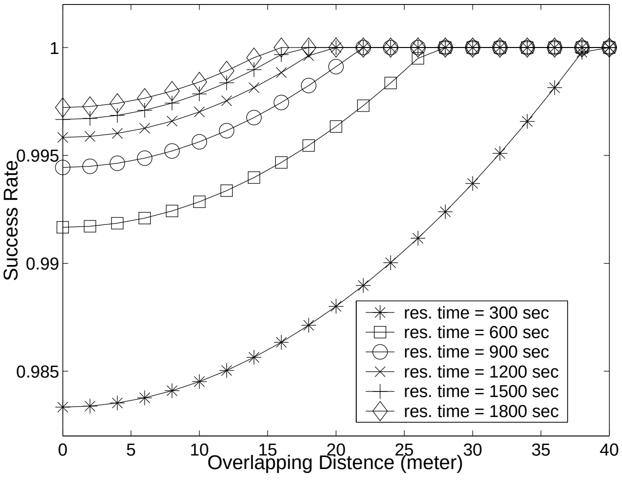

Fig. 8. Success rate against overlapping area for different residence time.

Another performance criteria is the residence time of MH in the subnet (T_{sub}^{res}) and in the overlapping area (T_{ovr}^{res}). For a given τ, the critical time (T_{cr}) varies with T_{ovr}^{res}, which in turn varies with d_{ovr} and T_{sub}^{res}. Fig. 8 shows the variation of success rate as a function of the overlapping distance for various residence times. For a given network latency of 0.5 seconds and T_S^d = 3 sec, if the overlapping distance varies betwee 0 and 40 meters and if T_{sub}^{res} varies between 300 sec to 1800 sec, we found out that the success rate remains one for d_{ovr} = 40 meters or above.

The residence time of MH in both the subnet and overlapping area are dependent on the subnet radius, Hence, for a given T_{sub}^{res} and τ, T_{cr} depends on T_{ovr}^{res}. If d_{sub} varies, the relative overlapping distance varies and so does T_{ovr}^{res}. Fig. 9 depicts the effect of subnet radius on varying overlapping area. For τ = 2 seconds, if the overlapping distance varies between 0 and 40 meters, T_{sub}^{res} remains at 600 sec. If d_{sub} varies between 250 to 750 meters, we found out that for d_{ovr} = 40 meters (or above), the success rate remains at one. Thus, we can conclude that within reasonable network latency and overlapping region, DNS is able to successfully serve as a LM.

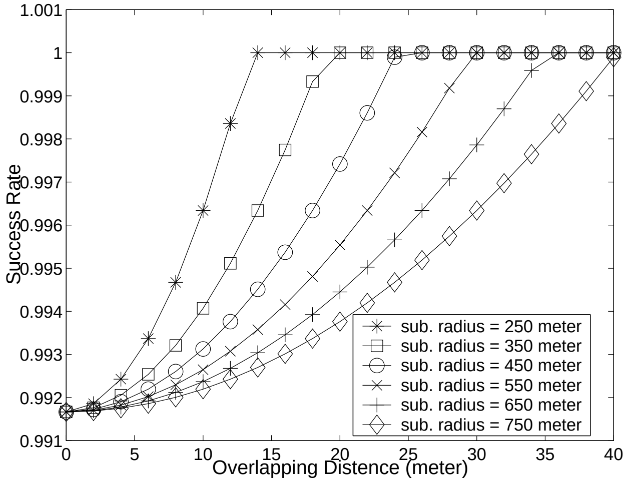

Fig. 9. Success rate against overlapping area for different subnet radius.

VII. CONCLUSIONS

Most of the connections in the Internet originate with a DNS lookup. DNS is an established and widely deployed technology in the Internet for name-to-IP address mapping of Internet hosts. We have investigated the possibility of using DNS as a Location Manager for `SIGMA`, an IP diversity based transport layer mobility management scheme for mobile data networks. In this paper, we developed an analytical model to study the performance of DNS as a location manager in terms of success rate, internet traffic load and subnet radius. Our results show that DNS is a feasible solution for location management even under some tough network and mobility scenarios.

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