Performance of DNS as Location Manager using Random Waypoint Model

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Abstract— **Domain Name System (DNS) can be deployed in the network as a Location Manager (LM) for mobility management. The suitability of DNS as a LM can be measured on how successfully it can serve to locate a mobile host. In this paper, we developed an analytical model to measure the performance of DNS as LM for mobility management techniques with IP Diversity support based on success rate which takes into account the Radius of the subnet, the residence time of MH in that subnet, latency in the network and the overlapping distance of 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 some high network latency.**

I. Introduction

Increasing demand for mobility in wireless data network has given rise to various mobility management schemes. Mobility management consists of two fundamental operations: Handoff and Location Management. Handoff occurs when a peripatetic (mobile) device changes its point of attachment while still continuing with the service that it has been providing. In a layered network architecture for data communications, handoff management can be managed at different layers. For example, Mobile IP (MIP) [1] is a network layer based handoff management scheme from IETF, MSOCKS [2] is a transport layer solution, and IEEE 802.11b [3] follows a Layer 2 solution for handoff. Location management refers to the task of locating (finding the IP address) a Mobile Host (MH) by a Correspondent Node (CN) in order to initiate and establish a connection. Location management should be transparent to the CN, and it should provide a valid address to the CN.

There are two common choices for implementing a Location Manager (LM) for the task of location management.

1) Dedicated Location Manager: A dedicated location manager is deployed specifically to perform location management operations. The benefit of this system is it can borrow concepts from already mature cellular networks. However, it suffers from the disadvantage of requiring significant changes in the IP network infrastructure, which gives rise to deployment issues in the Internet.
2) Domain Name System (DNS): DNS [4] provides name to IP mapping for locating a host in the Internet. Since almost all connection establishments start with a name lookup, it is possible for a DNS to serve as a LM. DNS is already a part of the existing Internet infrastructure and supports dynamic secure updates [5]; the real benefit of this scheme is that no change in the Internet is required to deploy a location manager for mobile data hosts.

The advantage of being able to deploy a LM without any change in the Internet infrastructure led us to investigate the suitability and performance of using DNS as a LM for mobility management as illustrated in Fig. 1 for a transport layer based mobility management scheme based on IP diversity. During the handoff process, the MH has two IP addresses one for each of the neighboring subnets and communicates with both the APs at the same time with multiple interface card which is becoming common for mobile devices. This support for multiple IP address is called IP diversity, and our location management technique will be illustrated using Seamless IP diversity based Generalized Mobility Architecture (`SIGMA`) [6]. `SIGMA` is a new handoff management technique which exploits IP diversity offered by multiple interfaces in mobile devices. When a 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

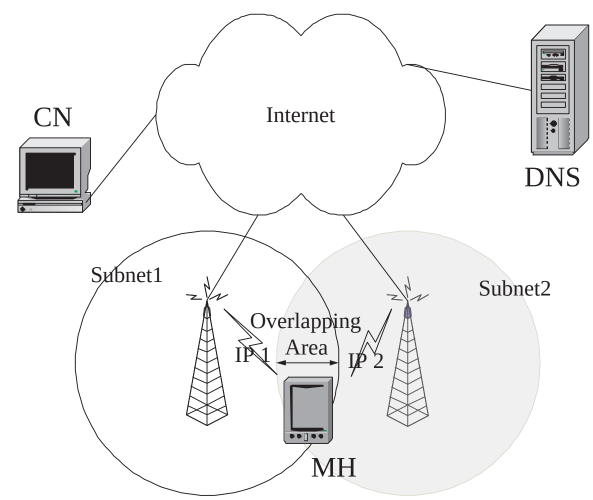

Fig. 1. DNS as a Location Manager.

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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.

The suitability and success of DNS as LM depends on how successfully it can locate a MH. Location queries to the DNS and updating of DNS with location information as MHs move cause control traffic which results in increased load on the DNS server. Moreover, failure to provide the correct IP address of the MH results in a query failure. This type of failure can occur when a CN obtains an address from the LM, but the MH hands off to a new point of attachment when the connection request from the CN arrives at the MH. This is due to the network delay between the time a query is resolved and the time of a connection request to the CN. The success rate of a LM is determined by the fraction of queries that result in a successful connection to the MH.

One of the earliest suggestions on using directory server for location management can be found in [7]. It suggests a graph theoretic regional matching to provide cheap locality preserving representations for arbitrary networks. But it does not discuss implementation technique in a real world scenario. A recent proposal [8] discusses the use of DNS as location management but lacks performance evaluation and consideration of challenges, such as *query failure* and higher traffic load, involved in using DNS as a LM. The *authors are not aware of any (including [7], [8]) previous study* on performance evaluation of 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) developing an analytical model to study the performance of DNS as LM, and (ii) identifying the impact of received power, MH velocity and network delay on query failure. The result of our analysis shows that within reasonable MH velocity and network latency, DNS can be used as LM with a high success rate.

The rest of the paper is organized as follows. Sec. II describes the deployment of DNS as a LM, Sec. III develops the analytical model for evaluation of DNS as a LM. Sec. IV shows results on performance of DNS as LM, followed by conclusions in sec. V.

II. DNS AND LOCATION MANAGEMENT

Domain Name System [4] is a distributed service that maps host names to corresponding IP addresses. All Internet Service Providers (ISP) maintain Local Name Servers (LNS) that cache recent name to IP mappings. Any subsequent request for the same name is served directly from the LNS. If the LNS does not have an entry for a 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. An ANS can provide addresses of the host of that sub domain. The name to 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 [4].

In the Internet, location of a host is synonymous to the current point of attachment of the host. The point of attachment is represented by the current IP address of the MH. Location management in a mobile data network is challenging as a MH continuously changes its point of attachment and hence its IP address. Basic functionality of a LM encompasses three operations: (i) *Location Update* which consists of updating the LM whenever a MH changes its point of attachment and acquires a new IP address; (ii) *Location Search* is querying the LM to find out the current location of the MH; this takes place before a CN initiates a communication with a MH; (iii) *Location Confirmation* is updating and confirming the location information of the MH at the CN [9].

A. Deployment of DNS as LM

Most of the connection setups generated in the Internet begin with a name lookup via the DNS [10], i.e. domain name is used as the identity of target host. This affirms the notion of considering DNS as a location manager as follows. Whenever a MH changes its point of attachment, it will register the new IP address with the Authoritative Name Server via dynamic secure update [5]. 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.

A LNS caches results of a DNS query for faster resolution of future queries. A cached record has a Time to Live (TTL) entry which is given by the ANS and represents the time after which the LNS should delete the entry; this results in the next query to be resolved by the ANS. 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 connections, instead of using cached DNS records at the LNS, query the ANS for the most recent location of the MH. This is required to avoid the CN using cached obsolete IP address of the MH. Caching at the LNS can be avoided by the ANS assigning a TTL value of zero; this will result in all queries to be resolved by the ANS, which has the most updated IP address of the MH.

A significant challenge in deploying DNS as LM is the extra network traffic and load on the server due to the *no-caching* policy resulting in all name lookup queries to come to the ANS. However, with today's hardware advancement, we expect the ANS to be able to handle the extra traffic as the web servers already handle an even higher volume of traffic. Another significant challenge related to deployment of DNS as a LM arises from the possibility of failure to update the DNS due to loss of DNS update messages. Dynamic Updates in the Domain Name System [11], which allows a device to dynamically update its Name-to-IP mapping at DNS and supports acknowledgement ensuring the safe delivery of the update packet can be used to solve the problem. The most significant challenge is during the handoff period. As shown in Fig. 2, 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. The effect of the above issue is minimized when the handoff process is based on IP Diversity, as in SIGMA, which enables a MH to have two IP addresses and maintain two data streams during the handoff period. In that case, if the connection request arrives *within* the overlapping zone, *even after the handoff*, the CN would be able to locate the MH with old IP address.

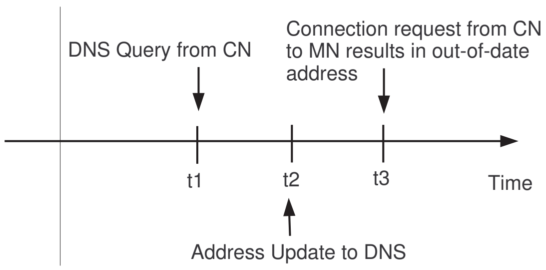

Fig. 2. Effect of obtaining out-of-date address by the CN.

B. DNS as Location Manager for IP Diversity based Mobility Management

We will illustrate the use of DNS as LM for an IP diversity based (e.g. SIGMA [6]) handoff. During the residence of the MH in the overlapping area, the DNS record corresponding to a MH contains two IP addresses of the MH, and the DNS serves both the IP addresses in response to a location query. The order in which the IP addresses are stored in the DNS record determines the priority of the IP addresses, i.e. the sequence to be used by the CN to address the MH for connection setup.

Fig. 3 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 (time t_4) 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. Later on, when the MH hands off based on relative signal qualities of the two access points (time t_5), it sends another update message with the new IP address as the first address followed by the old IP address. When the MH leaves the overlapping area (time t_6), it sends an update to the ANS to remove the old IP address. In the overlapping area, ANS responds to location queries with two addresses, the order being determined by the physical location of the MH in the overlapping area.

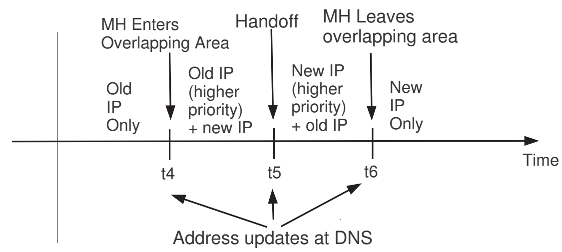

Fig. 3. MH's IP addresses in different stages of Handoff and their respective DNS updates.

III. Analytical Model for Performance Evaluation of DNS as LM

The primary success measure of a DNS as LM is determined by how successfully it can provide the CN with the appropriate 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 order to find that, in Sec. III-A, we derive the residence time of a MH in a subnet, in Sec. III-B, we derive the critical time during which location queries carries a possibility of failure, and in Sec. III-C we compute success rate based on traffic arrival rate to LM during its residence time and critical time.

A. Calculation of Residence Time

Mobile host moves according to Random Waypoint model [12], which is the most frequently used model in mobile networking research. In this mobility model, a MH randomly selects a destination point in the topology area according to uniform distribution, then moves towards this point at a random speed again uniformly selected between (v_{min}, v_{max}). This one 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 will stay stationary for a period of time, called *pause time*, after that a new epoch starts.

Let,

$E(T)$ = expected value of *epoch time*.

$E(P)$ = expected value of MH pause time between movements.

$E(L)$ = 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 MH in a subnet. With this parameter, we know the frequency for MH to change the point of attachment, and therefore the frequency of updating LM and CN. 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):

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

We first compute $E(T)$, since *epoch length* L and movement speed v 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} is minimum and maximum values of v.

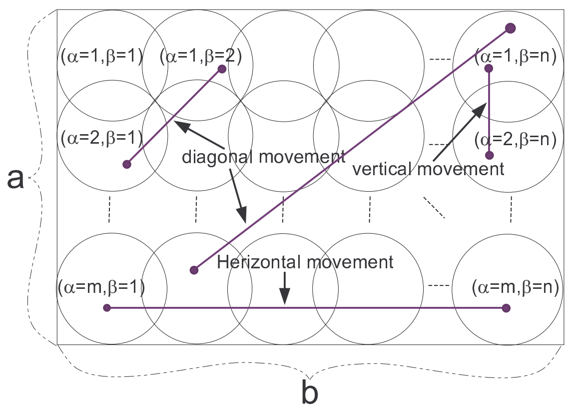

Fig. 4. Arrangement of subnets in a rectangular topology.

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, n are the number of vertically and horizontally arranged subnets in the topology, respectively. From [12], 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). Since pause time has been assumed to be uniformly distributed between (0, P_{max}), we have:

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

Here P_{max} is the maximum pause time.

Next, we need to find $E(C)$, the general form of which can be expressed as [12]:

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

$C\begin{pmatrix}(\alpha_i,\beta_i)\\(\alpha_j,\beta_j)\end{pmatrix}$ 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. $C\begin{pmatrix}(\alpha_i,\beta_i)\\(\alpha_j,\beta_j)\end{pmatrix}$ can be generalized by the following Manhattan distance metric:

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

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 the queries are processed at the ANS without any referrals. Then the process of communication initiation between a MH and CN has two parts. First the CN gets the Name to IP address mapping from the ANS, and then it initiates a connection with the MH with the IP as illustrated by the timeline in Fig. 5.

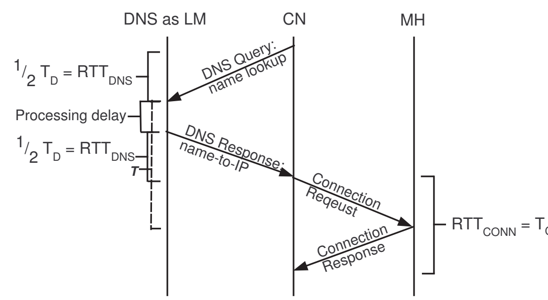

Fig. 5. Timeline of connection initiation from CN to MH.

We denote $\Delta t_{1+2} = t_5 - t_4$ and $\Delta t_{2+1} = t_6 - t_5$ as illustrated in Fig. 3. Here Δt_{1+2} is the time during which 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 spent by 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 a 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

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

Now, in the internet, the round trip delay is sum of round trip propagation delay, transmission delay and queuing delay. If

T^d_{CA} = Propagation delay between CN and ANS
T^d_{CM} = 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
$\frac{1}{2}T_D = T^d_{CA} + \frac{\psi_D}{\beta_{CA}} + \overline{\xi}$
and $\frac{1}{2}T_C = T^d_{CM} + \frac{\psi_C}{\beta_{CM}} + \overline{\xi}$
Therefore,

$$\tau = T^d_{CA} + T^d_{CM} + \frac{\psi_D}{\beta_{CA}} + \frac{\psi_C}{\beta_{CM}} + 2\overline{\xi} + T^d_S \qquad (11)$$

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

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

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

Now, if d_{sub} is radius of a subnet and d_{ovr} is the overlapping distance, 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 which basically reflects the distance of the MH from the center of the subnet [13]. Thus, Probability of a MH being within that subnet is $\int_0^{d_{sub}} f_x(x)dx = 1$ and Probability of the MH being in the overlapping zone 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 $x_{min} = d_{sub} - d_{ovr}$. Then if T^{res}_{ovr} is the residence time of MH in the overlapping zone, then $T^{res}_{ovr} = T^{res}_{sub}\int_{x_{min}}^{d_{sub}} f_x(x)dx$.

From Eqn. (9), essentially,

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

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

C. Calculation of Success Rate

Now, we can find the number of failures during a single handoff as E[$\chi(T_{cr})$] and total number of queries as $E[\chi(T^{res}_{sub})]$ 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 $E[\chi(T^{res}_{sub})] = \lambda T^{res}_{sub}$.

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

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

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

IV. Results

Eqn. (14) determines that the success rate for DNS as LM which depends on residence time of MH in a subnet and the critical time. Critical time is dependant on the latency in the network and the residence of MH in the overlapping region. Latency is dependant on propagation, transmission and queueing delay at the network. Overlapping distance and residence time of the MH gives the time during which it stays in the overlapping region. So, in short, the success rate depends on latency in the network, residence time of the MH and overlapping distance for a given subnet.

Thus, one of the performance measures is how the success rate varies over different overlapping distances. If the overlapping distance,d_{ovr}, is zero, then it would be more like Fig. 2, and as d_{ovr} increases, the possibility of locating the MH even with the old IP address increases. On the other hand, if the latency in the internet and the processing delay at server, τ, is very low, the probability of query failure is also very low. Here latency means the sum of propagation, transmission and queueing delays (Eqn. (11)). For a given residence time, T^{res}_{sub} = 300 sec, processing delay at server T^d_S = 3 sec and subnet radius d_{sub} = 500 meter, if the overlapping distance varies between 0 and 40 meters and if network latency varies from 0.3 to 1.8 seconds, we found out that for an overlapping distance of about 30 meters (or above), the success rate remains one as illustrated in Fig. 6.

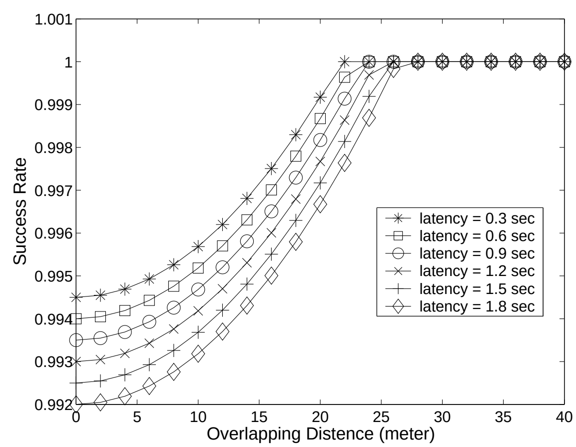

Fig. 6. Success rate against overlapping area for different network latency.

For the same configuration, if we have a fixed network latency of 0.5 sec while a varying T^d_S from 2 to 3.25 sec, we see from Fig. 7 that for an overlapping distance over 25 meters the success rate settles to one even with a high T^d_S of 3.25 sec.

Another performance measurement variable is the residence time of MH in the subnet. How quickly a MH crosses a subnet and an overlapping region determines the residence time of MH in the subnet (T^{res}_{sub}) and in the overlapping region (T^{res}_{ovr}), respectively. For a given τ in the network, critical time T_{cr} varies with T^{res}_{ovr}. T^{res}_{ovr} varies with d_{ovr} and T^{res}_{sub}. So, for a given latency of the 0.5 seconds in the network and T^d_S = 3 sec, if the overlapping distance varies within 0 and 40 meters and if T^{res}_{sub} varies from 300 sec to 1800 sec, we found out

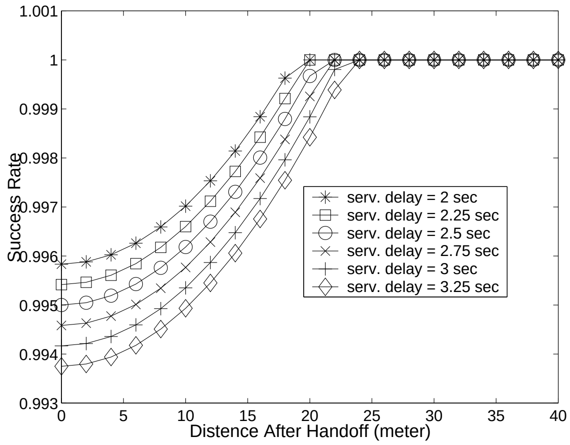

Fig. 7. Success rate against overlapping area for different query processing time at server.

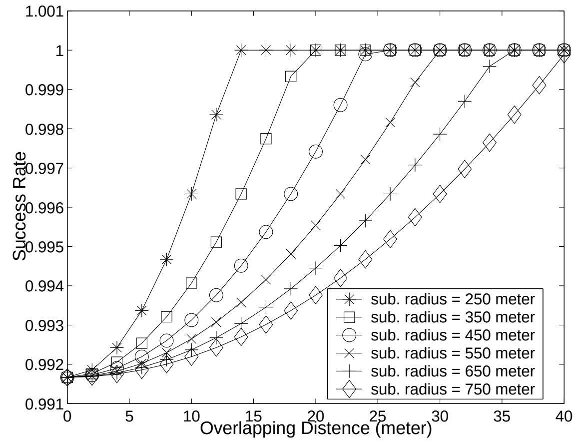

Fig. 9. Success rate against overlapping area for different subnet radius.

that for d_{ovr} = 40 meters (or above), the success rate remains one. Fig. 8 shows how success rate changes over overlapping distance with varying residence time.

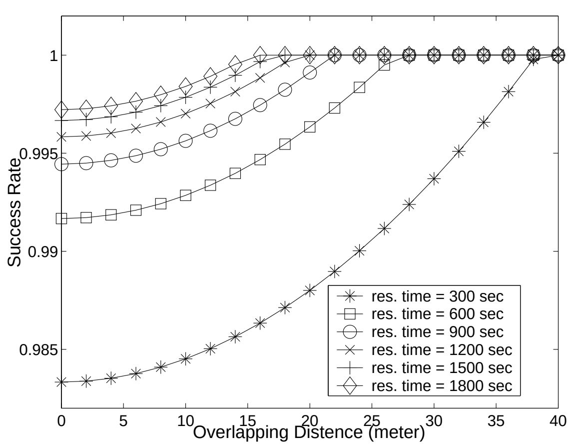

Fig. 8. Success rate against overlapping area for different residence time.

Now, as residence time of MH in both subnet and overlapping area is dependant on the subnet radius, if both T_{sub}^{res} and τ remains static, then T_{cr} would depend on T_{ovr}^{res}. If d_{sub} varies, then the relative overlapping would vary and so would T_{ovr}^{res}. So, for a given τ of the 2 seconds in the network, if the overlapping distance varies within 0 and 40 meters, T_{sub}^{res} remains at 600 sec and d_{sub} varies from 250 meters to 750 meters, we found out that for d_{ovr} = 40 meters (or above), we find that success rate remains one. Fig. 9 depicts the effect of subnet radius on varying overlapping area.

Thus we can conclude that within reasonable latency and overlapping region, DNS would be able to serve as a LM successfully.

V. Conclusions

DNS has been considered as a Location Manager as it is already an established technology implemented in the Internet and is the originator in most of the connections. Previous studies have not analyze the performance of DNS as a location manager in 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 clearly shows that DNS is a feasible solution for location management even under some tough network and mobility scenarios.

References

[1] C. Perkins, "IP mobility support." IETF RFC 3344, August 2002.

[2] D. A. Maltz and P. Bhagwat, "MSOCKS: an architecture for transport layer mobility," *IEEE INFOCOM*, San Francisco, CA, pp. 1037 – 1045, March 29 - April 2, 1998.

[3] LAN/MAN Standards Committee of IEEE Computer Soceity, "IEEE standard - local and metropolitan area networks- specific requirements- part 11: Wireless LAN medium access control (MAC) and physical layer (PHY) specifications: Higher-speed physical layer extension in the 2.4 GHz band." IEEE Std 802.11b-1999, 2000.

[4] P. Mockapetris, "Domain name - implementation and specification." IETF RFC 1035, November 1987.

[5] D. E. Eastlake, "Secure domain name system dynamic update." IETF RFC 2267, January 1998.

[6] S. Fu, L. Ma, M. Atiquzzaman, and Y. Lee, "Architecture and performance of SIGMA: A seamless handover scheme for data networks," *Accepted for presentation at ICC*, Seoul, South Korea, May 16-20, 2005.

[7] B. Awerbuch and D. Peleg, "Concurrent online tracking of mobile users," *Computer Communication Review*, vol. 21, no. 4, pp. 221–233, September 1991.

[8] A. C. Snoeren and H. Balakrishnan, "An end-to-end approach to host mobility," *MOBICOM*, Boston, MA, pp. 155 – 166, August 6-11, 2000.

[9] P. Krishna, N. H. Vaidya, and D. K. Pradhan, "Location management in distributed mobile environments," *Third International Conference on Parallel and Distributed Information Systems*, Austin, TX, pp. 81 – 88, September 1994.

[10] J. Jung, A. W. Berger, and H. Balakrishnan, "Modeling TTL-based Internet caches," *IEEE INFOCOM*, San Francisco, CA, pp. 417 – 426, March 30 - April 3, 2003.

[11] P. Vixie, "Dynamic updates in the domain name system." IETF RFC 2136, April 1997.

[12] C. Bettstetter, H. Hartenstein, and X. Perez-Costa, "Stochastic properties of the random waypoint mobility model: epoch length, direction distribution, and cell change rate," *ACM International Workshop on Modeling Analysis and Simulation of Wireless and Mobile Systems*, pp. 7–14, September 28, 2002.

[13] C. Bettstetter, H. Hartenstein, and X. Prez-Costa, "Stochastic properties of the random waypoint mobility model," *Wireless Networks*, vol. 10, no. 5, pp. 555–567, September 2004.