NDN, Technical Report NDN-0013, 2013. http://named-data.net/techreports.html
Revision 1: July 9, 2013

A New Perspective on Mobility Support

Zhenkai Zhu, Alexander Afanasyev, Lixia Zhang
Computer Science Department
University of California, Los Angeles
{zhenkai, afanasev, lixia}@cs.ucla.edu

ABSTRACT

As the number of mobile users proliferates, there is an ever increasing demand for Internet mobility support to meet the applications' need. Although years of research on IP mobility support has produced a rich literature of solutions, few of them are widely adopted. Concerns regarding the existing solutions range from inflexible communication models to weak security measures. Furthermore, these solutions are based on the assumption that a mobile node is always connected to the infrastructure, and its movement only results in different connecting points. In reality, however, mobility often leads to intermittent connectivity (e.g., vehicles on the road) or opportunistic ad hoc connectivity among a set of mobile nodes. In this paper, we align mobility support with the data-centric nature of applications in Named Data Networking (NDN) architecture and provide a new perspective on mobility support that addresses the weakness in the existing IP mobility solutions as well as utilizes lessons learned.

1. INTRODUCTION

Over the last two decades, many efforts have been devoted to developing solutions for IP mobility support, resulting in a wide variety of proposed protocols [22], some of which have become the Internet standards. The basic question addressed by IP mobility support is how to deliver packets to the mobile node and how to maintain the transport and higher layer connections in the presence of the mobile's location changes. To achieve these goals, a mobile usually gets assigned a stable identifier, usually an IP address, which is used in transport protocols and remains unchanged while the mobile moves. To enable other nodes to reach the mobile in movement, the mobile must propagate its location via the routing system or employ a third-party node (e.g., home agent in Mobile IP [15, 9]) to maintain an up-to-date mapping between the mobile's stable identifier and the current IP address that can be used to reach the mobile.

Yet, despite of years of research efforts in IP mobility support, none of the proposed IP mobility solutions has seen wide deployment. Concerns were raised regarding the inflexible communication model (focusing only on maintaining long-term host-to-host connections), the weak security measures, the potential sub-optimal data paths, and performance bottleneck at the critical third-party nodes such as home agents [16]. Moreover, almost all of the existing IP mobility solutions are based on a rather limiting assumption that a mobile node only moves between different connecting points to the infrastructure. In reality, the movement of a mobile node easily leads to intermittent connectivity even in areas with wireless coverage, or encountering a set of mobile nodes that have ad hoc connectivity among themselves. Due to the limited scope of IP mobility solutions, separate branches of networking research, delay-tolerant networking (DTN) and mobile ad hoc network (MANET), have been created to handle these problems left out by IP mobility support, each with their own set of solutions that are largely orthogonal and incompatible with IP mobility solutions. As a result, an application running on the mobile node may need to switch from a TCP-based application protocol running over 4G to probably a UDP-based DTN protocol when the connectivity condition changes. This is, in part, a testament to the failure of the existing solutions to be able to support mobile communications under varying connectivity conditions, which a mobile usually experiences when roaming.

Can one provide flexible, secure, and yet simple mobility support that serves the applications need in mobile environment? Our answer is a resounding yes. The basic reason behind various shortcomings of IP mobility support is that previous attempts typically incorporated TCP/IP's host-centric, point-to-point communication model, which does not fit the dynamic mobile networking environment and fails to accommodate emerging communication patterns.

Meisel et al. [12] were the first to argue that MANET can be made more effective and efficient through Named Data Networking (NDN) [11], a proposed future Internet architecture that transforms data into a first-class entity. [12] observed that MANET solutions typically adopted basic models from the existing Internet protocol stack which was designed for wire-connected network topology, and thus unsuited for the highly dynamic, ad hoc MANET environment. The authors then demonstrated that using named-data approach for data delivery in MANET can better utilize the broadcast nature of wireless channels and can effectively and efficiently handle both physical mobility of nodes and logical mobility of application data.

In this paper, we take a further step forward and assess the overall picture of mobility support in NDN. By aligning the mobility support with the data-centric nature of applications' requirements, the name-based data retrieval in NDN design, and the broadcast nature of wireless medium, we provide a new perspective on mobility support that addresses the weakness in the existing IP mobility solutions as well as utilizes lessons learned. Not only can the NDN architecture address the concerns in today's IP mobility solutions, but it also can integrate mobility support using the same approach to cover all connectivity conditions in mobile environment, including ad hoc and delay-tolerant networks.

The paper is organized as follows. Section 2 presents an overview of the existing IP mobility solutions and their limitations. In Section 3, we briefly introduce the NDN architecture. We discuss our new perspective on mobility support in Section 4. We discuss related work in Section 5 and conclude the paper in Section 6. We use various vehicle networking scenarios as illustrative examples throughout the paper, but we believe our observations and conclusions are applicable to other mobile devices in general.

2. IP MOBILITY SUPPORT SOLUTIONS

In this section we discuss the solution space of IP mobility support and identify its limitations.

2.1 Solution space

All existing IP mobility support designs can be broadly classified into two basic approaches: routing-based approach and mapping-based approach.

Connexion [3] and WINMO [7] represent the first approach to mobility support. A mobile keeps the same IP address regardless of its location changes, and the IP address can be used both to identify the mobile and to deliver packets to it. To ensure that at any given moment packets carrying the mobile's stable IP address can be delivered to the right place, the routing system must continuously keep track of mobiles' movements and reflect their current positions in the network on the routing table. Supporting mobility through dynamic routing is conceptually simple. It can also provide robust and efficient packet forwarding, assuming that the routing system can keep up with the mobile movements. However, because the entire network must be informed of every movement by every mobile, this approach raises serious concerns on the scalability when applied to large networks [1], and thus works well only in small networks with a small number of mobiles.

The second approach to mobility support is to provide a mapping between a mobile's stable IP address and its dynamically changing IP address. Instead of notifying the world on every movement, a mobile only needs to update the mapping service about its location changes. This is the approach taken by the majority of the IP mobility solutions,[1] including Mobile IP [15, 9] and its extensions. If one level of indirection at IP layer is used, as in the case of Mobile IP, there is a potential side effect of introducing triangle routing. In alternative DNS-based approaches, such as in [18, 4, 13], both ends are aware of the mobile's movement, but they can use direct data path in between for packet exchanges.

[1]Cellular solutions also fall into this category.

2.2 Limitations

Although the existing IP mobility solutions differ in many ways, nonetheless they share several common limitations as we list below.

First, as IP is designed for point-to-point data delivery, so far the IP mobility solutions also focus only on maintaining point-to-point communication sessions. However, in the face of the increasing popularity of other communication patterns, such as information-centric and many-to-many group communications, the model inherited from IP greatly limits the capability of applications built on top of IP mobility solutions.

Second, security has always been a big challenge. Like the prevailing practice of securing the communication channels in the current Internet, the security in IP mobility solutions is tied to IP addresses. This means that the security associations must be updated or reestablished when one or both ends move, which is inefficient and fragile in mobility scenarios where devices tend to move around frequently. Also, once the other end is authenticated and the communication channel is established, whatever data comes from the channel is regarded as from the node that one intends to communicate with. However, this is vulnerable in practice as protocol designs tend to treat security as the "add-on" features and often use very basic measures that are easily broken [16]. For example, Mobile IPv6 [9] uses a *"return routability procedure"* to protect the location update from the mobile to the correspondent node, which simply checks whether the sender of the location update message is in fact reachable using the claimed new care-of address and the home address.

Last but not least, a basic assumption of IP mobility solutions is that the mobile always has connectivity to the infrastructure. However, in reality the mobility can easily lead to intermittent connectivity or ad hoc connectivity among a set of mobiles. Such problems are currently handled by DTN and MANET respectively, which creates a great hurdle for applications to work under any connectivity conditions.

3. NDN ARCHITECTURE

We briefly introduce the basic concepts of NDN architecture that are essential for the discussion of our new perspective on mobility support.

NDN is a proposed future Internet architecture [11], that uses data names instead of host addresses for data delivery. This conceptually simple but architecturally fundamental departure from TCP/IP enables NDN to meet the challenges faced in supporting mobility, including efficient use of broadcast wireless media, seamless use of multiple interfaces, flexible data fetching, and the inclusion of intrinsic security building blocks.

NDN incorporates principles that have made the IP protocol suite widely adopted and globally scaled (e.g., the hourglass design and end-to-end principle), but changes the fundamental layer of the architecture to one better suited to modern networks and emerging communication patterns. NDN replaces IP's point-point communication model with receiver-driven data delivery based on application-specified names. That is, applications send out Interest packets which contain the names of the desired data. The network forwards Interest packets directly on these names, using optional hierarchy in the namespaces to support routing scalability. Depending on network settings, the Interest packets may be forwarded along multiple paths towards potential location of the data, and pull the data via the reverse paths of Interests down to the requesters. This approach, along with NDN's per-packet content signatures, permits any node in the network to cache named data packets and respond to requests for them.

4. MOBILITY SUPPORT IN NDN

NDN is particularly beneficial in providing mobility support. Mobile nodes can communicate based on what data they need, instead of trying to maintain a specific path to reach a specific node. In this section, we show that NDN, with its ability to name individual content packet, to securely bind name to the content, to keep per-packet state in forwarders, and to have flexible Interest forwarding strategy at each node, can greatly simplify the mobility support design in various aspects.

4.1 Location independent data security

NDN secures the data itself, a design choice that decouples trust in data from the trust in hosts (or locations). This simple yet transformational shift is of tremendous significance in mobility support. The difficult problem of securing the ever-changing communication channels and all the boxes along the way no longer exists. Instead, one only needs to concern about the security of the data itself. The task of providing provenance is achieved by the per-packet signatures and the data secrecy, if needed, is accomplished by encryption, leaving open only the task of trust management between data producers and consumers, but not the dependency on any channels or boxes in the middle of the dynamic data delivery paths.

4.2 Enhance delivery with network caching

Because each data packet in an NDN network is named and signed, it can be cached in any node and used to satisfy later requests. NDN's built-in caching support can bring great opportunities to enhance data delivery in dynamic environment through opportunistic caching by any nodes.

First, when the network paths are dynamic and unpredictable traditional caching approaches, which cache the whole application level data objects rather than segments of objects, work poorly or not at all in dynamic environments. This is due to the fact that each cached objects has to be retrieved in its entirety from the same caching node. However, given that application-level data objects, e.g., images, videos, tend to be large in size, it is often the case that the data paths changes mid of fetching a big object, resulting in wasted effort. In NDN, since each data packet is meaningful independent of where it comes from or where it may be forwarded to, different chunks of the same large application data object can be opportunistically stored at multiple intermediate

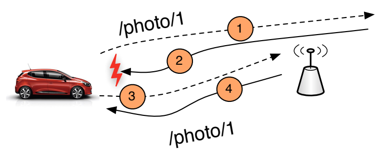
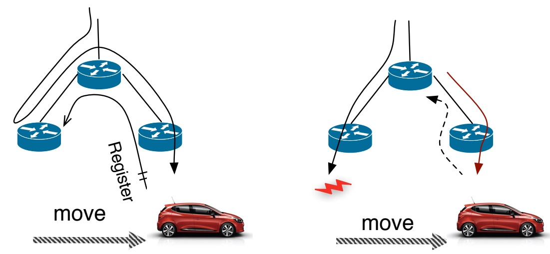


Figure 1: Recover last hop packet losses



(a) optimization of handoff in IP by tunneling data

(b) caching helps smoothen handoff in NDN

Figure 2: Handoffs in IP and NDN

nodes to speed up future requests. Content or infrastructure providers can also set up designated long-term caching nodes for popular content, and it is entirely likely that some of the mobile user's requests get satisfied by caches on one node and others by a different node as a result of movement.

Furthermore, NDN caching also improves the performance in noisy wireless environment and smoothens the mobile's handoff. For example, as shown in Figure 1, the packets that are lost in last wireless hop are cached in the access point and can immediately satisfy the retransmitted Interests from the mobile, without the need to go all the way to the content provider again. Also, smooth handoff is achieved without special optimization techniques, which are required in IP mobility solutions. For instance in IP, a mobile need to ask the old access router to tunnel packets to the new access router during the handoff (see Figure 2a). This usually imposes additional requirements on connectivity (e.g., a mobile may need to connect to both old and new access routers at the same time), requires both routers and the mobile to support special protocols, and potentially results in sub-optimal data paths. On the contrary, as shown in Figure 2b, the NDN data packets that are not delivered to the mobile during the handoff are opportunistically cached in the network and can be retrieved when the mobile retransmits the previous Interests from the new access router.

4.3 Integrating DTN and MANET into mobility support

Generally speaking, in an ad hoc or delay-tolerant environment, the distinction between routers and end hosts is blurred, as every node may need to help forward packet for other nodes. NDN automatically embraces ad hoc and delay-tolerant data delivery, rather than handling them by separate sets of solutions as in today's Internet. It achieves so as follows.

First, NDN names individual data pieces and routes Interests based on application-defined names rather than network

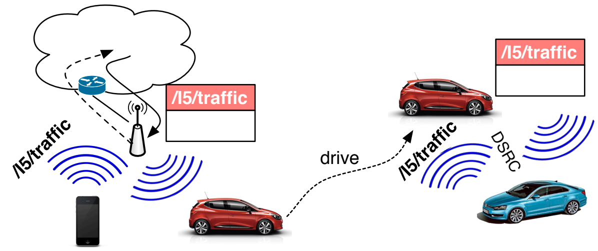


Figure 3: An example of unified handling of DTN and connected networks

driven conventions. This enables mobile nodes to communicate based on what data they need, instead of computing a path to reach a specific node. Also, data can be cached and carried around by mobile nodes. Second, NDN fully utilizes the broadcast nature of wireless communications. The Interests can be broadcasted and whoever has the answer can reply; the overheard data can be cached by a node. Finally, it operates over any transport that can deliver datagrams, and has no dependency on IP, although it can fully utilize IP connectivity when available. This allows mobile nodes to issue requests for data as soon as they have connectivity and without host address assignment.

Thus, DTN and MANET support is embedded in the NDN architecture and the communication model remains the same regardless of the types of networks, which greatly simplifies the mobile application designs. The example shown in Figure 3 illustrates how mobile communication under different connectivity conditions is supported in NDN. A mobile phone uses WiFi to request traffic information. The reply to this requests happens to be overheard by a car, which opportunistically caches it for potential future use. Later, if the car encounters other cars, it can use the cached data to reply their requests for the same traffic information, even in an open field without wireless coverage using Dedicated Short Range Communications (DSRC) [10, 20].

4.4 Support of mobile data consumers

Supporting mobile consumers in IP mobility solutions is not trivial. As a requirement of IP's host-to-host communication model, the consumers have to acquire IP addresses, set up connections or sessions, and perform updates whenever the IP addresses change.

NDN's receiver-driven communication model supports the mobile consumers in a straightforward way without creating unnecessary hassles. A consumer can send out request for data directly without address assignment or connection setup. When the Interest travels to the data producer, it sets up a temporary reverse path between the consumer and the producer, along which the corresponding data packet flows back. Such per-packet reverse paths are set up on-demand, short-lived (approximately the same to the round trip time), and are cleared once the the desired data packets come back. Hence, even if the consumers are on move, not a single entity is required to perform any kind of special operations. As depicted in Figure 4, the data naturally follows a different reverse path to the consumer after it moves.

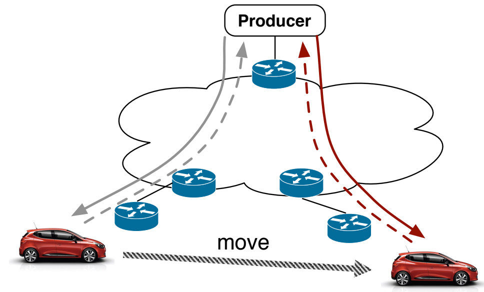


Figure 4: Data flows back to a mobile consumer along the reverse paths of Interests

4.5 Support of mobile data producers

In NDN, the network needs to route Interests based on data names. Unless the mobile producers dynamically announce their namespaces via routing system, mobile producers must have a way for Interests to reach them.

The invaluable lessons learned from IP mobility support research can be applied to solve the problem. Each mobile producer can be assigned a namespace, such as `/twitter/foo`, under which it publishes its data regardless of its location. Such a namespace can be used as the stable identifier for the mobile. The locator, on the other hand, can be a name that indicates the location of the mobile (e.g. the name prefix announced by the access network). The mapping between the identifier and the locator can be provided either by broadcasting or intermediate nodes such as DNS servers.

NDN is broadcast friendly. Interests are relatively small in size, making it feasible to broadcast Interests in a restricted domain in order to track the location of a mobile producer. Moreover, if multiple consumers are interested in fetching data from a mobile producer, only one Interest would be broadcasted and the data that describes the location of the mobile would be multicasted to all consumers. Figure 5 illustrates an example where three consumers utilize broadcast Interests to track a mobile producer. Thus, it is the simplest and most robust way to support mobility in a broadcast domain (a small network or a broadcast overlay spanning over large networks).

The broadcast approach has even more advantages if the communication media is broadcast in nature, such as the wireless LAN, where only one Interest-Data exchange is needed even if there are multiple consumers interested in fetching the mobile producer's data.

When the broadcast is not feasible, DNS can be exploited to store the mapping between the mobile's namespace and its location. An example of DNS-based approach is shown in Figure 6. When the user with `/twitter/foo` namespace is visiting Stanford campus, he can discover the name prefix of the Stanford network and update the location field of the DNS record to be `/stanford`. To fetch this user's data, a consumer queries DNS and sends an Interest `/twitter/foo/tweets/95` using the returned location name `/stanford` as *forwarding hint* [2], which is not a part of the data name being requested but indicates a suggested direction for routers to forward the Interests towards the mobile producer.

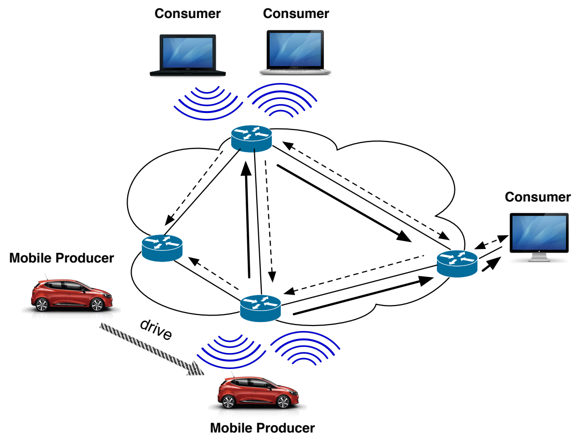


Figure 5: Consumers track a mobile producer using broadcast Interests, where dashed arrows are Interests and solid arrows are Data packets

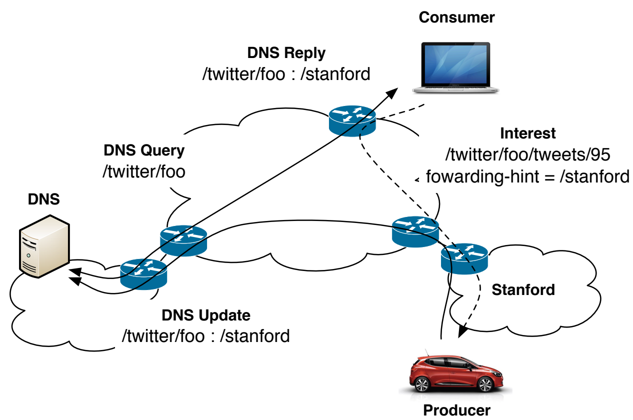


Figure 6: A consumer fetches data of a mobile producer using DNS-based approach

4.6 The power of data fetching strategies

The requirements for data fetching may vary a lot depending on application scenarios. Some may wish to have reliable delivery; some may wish to fetch content in spite of intermittent connection due mobility or power off; some may wish to use whichever interface that has best connectivity or to use all interfaces simultaneously.

NDN's *forwarding strategy*, which determines how alternative paths are utilized, suits well for such requirements on flexibility. This is enabled by the per-packet statistics and loop-free Interest forwarding, and it also takes into account different properties of the interfaces (e.g., whether it is a broadcast interface or whether the connectivity is free) and namespaces when determining the strategy of Interest forwarding. Thus, instead of a one-size-fits-all approach, different strategies could be designed to satisfy different requirements.

For example, to exploit multiple interfaces, a strategy may occasionally send the same Interests out via multiple interfaces (since there is no danger of looping) and run experiments to obtain round-trip delays of different interfaces, and then decide which one to use until it is time for the next experiment [21], as illustrated in Figure 7. Or different Interests could be sent out through different interfaces simultaneously, the portions adjusted according to the measured delays and the cost, in order to utilize all the interfaces.

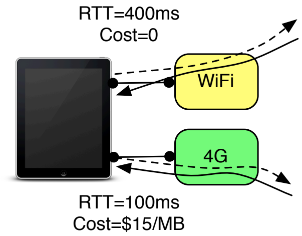


Figure 7: Utilizing multiple interfaces

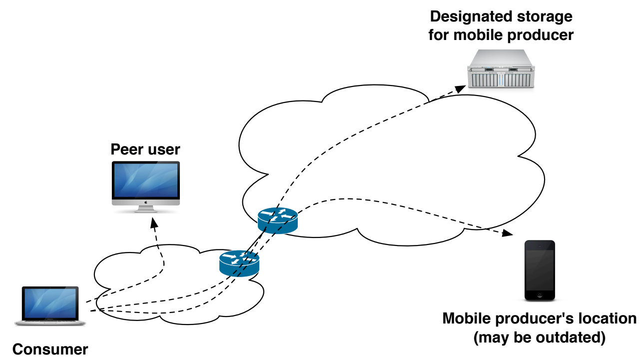


Figure 8: A consumer runs experiments to determine the best way to retrieve data generated by a mobile producer

Another example is to explore alternative means of fetching data produced by mobiles. Various means can be adopted by the strategy. It could first use local broadcast Interest to see if the data is already cached nearby by some peer consumers. It may send Interests directly towards to mobile producers use the most recent known “locations” reported by the mobiles (which may be obsoleted as the mobiles may not even have connectivity at the time). If the mobile has some designated storage servers to backup its data, the consumer may also send Interests to such servers. In fact, the consumer could also run experiments, as shown in Figure 8, by occasionally employing all these measures simultaneously to determine the best way of Interests dispatching in order to increase the chance of successful data fetching with minimal delay.

5. RELATED WORK

Meisel et al. [12] criticized the current practice of using the Internet protocol stack in the wireless ad hoc networks and argued that mobile ad hoc networks can be made more effective and efficient through NDN. A few early studies have shown promising results. For example, an NDN implementation (CCNx) was shown in [14] to outperform DHT-based solutions in a MANET scenario. Etafia et al. [5] further demonstrated NDN's superior performance in a mobile lossy environment compared to TCP/IP protocol suite.

Tyson et al. [19] surveyed several new Internet architecture projects and identified benefits and challenges brought from transforming into information-centric communication in terms of mobility support.

Several proposals [6, 8, 17] has been published to handle the mobility in NDN. However, they mainly focused on traditional point-to-point communication scenarios and tried to directly map the IP mobility solutions onto NDN. Their perspective on mobility support resembles those of the IP mobility solutions and did not fully take the advantages brought by NDN's transformational architectural shift.

6. CONCLUSION

In this paper, we provided a new perspective on providing mobility support to a vast number of mobile devices. Traditional IP mobility support suffers from various shortcomings as a result of TCP/IP's host-centric communication and addressing model, which does not fit the dynamic mobile networking environment and fails to accommodate emerging communication patterns. NDN, on the other hand, greatly simplifies the design for mobility support as it replaces IP's point-to-point communication model with receiver driven data delivery based on application-specified names. As a result, mobile nodes are no longer mandated to acquire IP addresses, which keep changing during the movement, or to maintain a dynamic path to a single node, enabling efficient use of broadcast wireless media, seamless use of multiple interfaces, and natural support of mobile consumers. Each piece of data is named and signed, and hence can be cached in the network, greatly enhancing delivery in dynamic environment and providing intrinsic security that is no longer dependent on locations. With such features, it is straightforward to integrate DTN and MANET into mobility support and the communication models remains the same regardless of the types of the network. NDN faces similar problems as those in IP mobility support for mobile producers, because the scaling problem of routing table size still exists despite that NDN routes on names. The invaluable lessons learned from IP mobility support research can be applied to solve the problem, and the flexible strategies allow consumers to devise best approach to increase the chance of successful data fetching from mobile providers.

7. REFERENCES

[1] Bgp update report. http://www.nanog.org/mailinglist/mailarchives/old_archive/2006-09/msg00119.html.

[2] A. Afanasyev, C. Yi, L. Wang, B. Zhang, and L. Zhang. Scaling NDN routing. *NDN Technical Report NDN-0004*, 2012.

[3] L. Andrew. A border gateway protocol 4 (BGP-4). 2006.

[4] S. Cheshire, Z. Zhu, R. Wakikawa, and L. Zhang. Understanding Apple's Back to My Mac (BTMM) service. *IETF RFC 6281*, June 2011.

[5] B. Etefia, M. Gerla, and L. Zhang. Supporting military communications with named data networking: an emulation analysis. *MILCOM '12*, 2012.

[6] F. Hermans, E. Ngai, and P. Gunningberg. Global source mobility in the content-centric networking architecture. *Proceeds of the 1st ACM workshop on Emerging Name-Oriented Mobile Networking Design*, 2012.

[7] X. Hu, M. Mao, and Y. Yang. Wide-area IP network mobility. *IEEE INFOCOM'08*, 2008.

[8] D. hyung Kim, J. hwan Kim, Y. sung Kim, H. soo Yoon, and I. Yoem. Mobility support in content centric networks. *Proceeds of the second edition of the ICN workshop on Information-centric networking*, 2012.

[9] D. Johnson, C. Perkins, and J. Arkko. Mobility support in ipv6. *IETF RFC 3775*, June 2004.

[10] J. B. Kenney. Dedicated short-range communications (DSRC) standards in the United States. volume 99, pages 1162 – 1182, July 2011.

[11] L. Zhang et al. Named data networking (NDN) project. *NDN Techincal Report NDN-0001*, October 2010.

[12] M. Meisel, V. Pappas, and L. Zhang. Ad hoc networking via named data. *MobiArch'10*, September 2010.

[13] R. Moskowitz, P. Nikander, P. Jokela, and T. Henderson. Host identity protocol. *IETF RFC 5201*, April 2008.

[14] S. OH, D. Lau, and M. Gerla. Content centric networking in tactical and emergency manets. *Wireless Days IFIP, '10*, 2010.

[15] C. Perkins. IP mobility support for IPv4. *IETF RFC 3220*, January 2002.

[16] K. Ramachandran. Mobile IP - deployment after a decade. 2006.

[17] R. Ravindrant, S. Lo, X. Zhang, and G. Wang. Supporting seamless mobility in named data networking. *5th Internation workshop on the Network of the Future*, 2012.

[18] A. Snoeren and H. Balakrishnan. An end-to-end approach to host mobility. *ACM Mobicom*, 2000.

[19] G. Tyson, N. Sastry, and I. Rimac. A survey of mobility in information-centric networks: challenges and research directions. *Proceeds of the 1st ACM workshop on Emerging Name-Oriented Mobile Networking Design*, 2012.

[20] L. Wang, A. Afanasyev, R. Kuntz, R. Vuyyuru, R. Wakikawa, and L. Zhang. Rapid traffic information dissemination using named data. In *Proc. of NoM'12*, 2012.

[21] C. Yi, A. Afanasyev, I. Moiseenko, L. Wang, B. Zhang, and L. Zhang. A case for stateful forwarding plane. *Computer Communications*, 36(7), 2013.

[22] Z. Zhu, R. Wakikawa, and L. Zhang. A survey of mobility support in the Internet. *IETF RFC 6301*, July 2011.