Supporting Mobility Mechanisms in NovelContent Centric Networks

Daniel Corujo, Rui L. Aguiar

***Abstract* –There is a large set of efforts on the definition of new Internet architectures. One of the currently more relevant is the CCN, content-centric networking, architectural concept. This type of architectures is focused on file transferral and fail to address real time multimedia communications in mobile environments. This paper discusses the mobility mechanisms to improve the design of CCNs for interactive mobile systems, presenting three different architectural approaches.**

Keywords: Content, content-centric networking, network named content, future internet, mobility

I. INTRODUCTION

Today's usage of the Internet, at least in terms of users, revolves around accessing content. Following an evolutionary path, E-Mail gave way to the World Wide Web (WWW) with content being browsed in web pages. Now, with YouTube and the social-networking paradigm being leveraged by the Web2.0, multimedia content is at a central plane and is ever increasing with new traffic tendencies [1]. This trend has been explored in many research activities [8-9] and even European Research Projects are considering it [2]. However, the underlying framework which supports this access content, the Internet, was created to access machines and resources therein. Thus, to support today's content access, the users have to endure application-specific mechanisms like Content Delivery Networks (CDN) and Peer-to-Peer (P2P), which aim to overcome the original model limitations, but which also introduce new issues such as security (i.e., trustworthy content), location-dependence (i.e., content to host mapping) and availability (i.e., bandwidth, etc.).

With the advent of Future Internet initiatives, new clean-slate approaches are being introduced, such as Content-Centric Networking (CCN) [3] or Named Data Networking [7] aiming to not only solve the abovementioned issues, but to completely replace today's architecture of finding hosts to reach content, by an architecture that is completely content name driven. Even though the CCN proposal has been successfully tested against voice traffic with interesting results [4], no work has been done considering mobility models which are a key area as well of Future Internet research.

As such, we expand the work developed at the Palo Alto Research Center (PARC) on CCN with intrinsic mobility prediction mechanisms, allowing the networking named content concept to flow in an optimized way under mobility-driven environments.

The remainder of this document is organized as follows. In Section 2 a brief description of the base functioning of the CCN concept is described, followed by Section 3 where its application for Voice over IP (VoIP) is presented. In Section 4 the predictive mobility optimization design is discussed, and the document ends in Section 5 with conclusions and Future Work.

II. CONTENT-CENTRIC NETWORKING FUNDAMENTALS

In the CCN concepts, the communication architecture is built on named data, where packets name content, and the communication itself is driven by the consumers of data. In that aspect, CCNs are quite different of the current IP architectures.

A. Communication Model

In order to provide this "named packet" behavior, the architecture introduces two kinds of CCN packet types: a Interest packet and a Data packet.

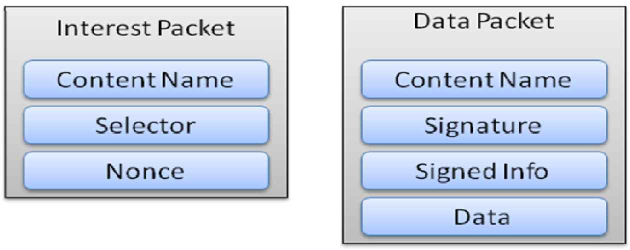

Figure 1. CCN packet types

The Interest packet is used by a consumer to ask for content by broadcast over all available connections. When this Interest packet reaches any node that has the requested data, it can respond with the correspondent Data packet. In this process, the Interest packet is consumed. Another interesting feature allowed by this model is that, through the pairing of Interest and Data packets, multiple nodes can pronounce themselves as interested in the same content, sharing transmissions over a broadcast medium. Packets are also able to be forwarded not only over hardware network interfaces, but also exchanged through application processes within a machine directly. CCN packets do not change over time and are self-identifying as well as self-authenticating.

The CCN data model features a forwarding engine which is responsible for performing actions towards a received packet, after a match look-up is done on its name. A schematic taken from [3] is presented in Fig. 2.

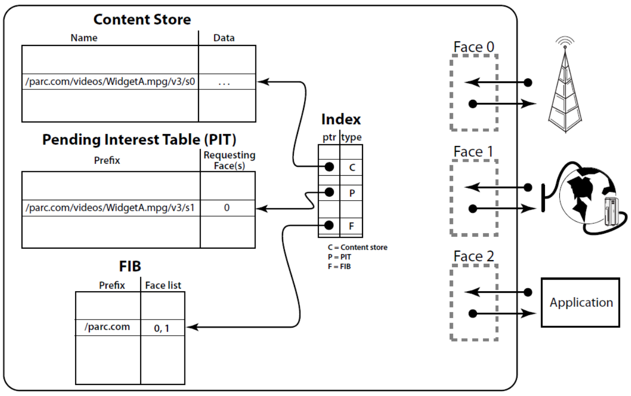

Figure 2. CCN forwarding engine model (from [3])

The CCN forwarding engine model is composed by three distinct entities: the Forwarding Information Base (FIB), the Content Store and the Pending Interest Table (PIT).

The purpose of the FIB is to forward Interest packets toward potential sources of matching Data. Here, sources is plural, because CCN allows multiple sources for data and is able to query them all in parallel, and thus a traditional spanning tree model is not used.

The Content Store acts as buffer memory that does not discard packets as long as it can, since they might be useful to other consumers, minimizing upstream bandwidth delay.

Finally, the PIT keeps track of Interest packets that where forwarded upstream towards content sources, allowing for Data packets to be sent downstream to their requesters. In this model, only Interest packets are routed and as they propagate they leave PIT entries in the nodes they are forwarded from, for matching Data packets to follow towards the requesters. These entries are deleted whenever a Data packet uses them to learn the next hop towards its requester. The PIT entries that never find a matching Data packet, eventually timeout to clear space. In this way, all nodes are able to provide caching, being only subject to their particular resource availabilities and/or policies. A flowchart diagram was created in order to explain the behavior described in [3] (see Fig. 3)

Whenever a CCN packet arrives at a node through an interface (either a network interface or an internal packet between processes) it is evaluated to determine if it's a Interest or Data Packet.

In case of an **Interest** packet, a longest match name lookup is done on the content name against entries in the previously mentioned main data structures:

- First, the lookup is done for matching entries in the Content Store. If one is available, the correspondent Data packet is sent through the same interface where the Interested packet came from.
- If there was no match in the Content Store, a match is done for an entry in the PIT. In case of a positive match, the Interest's arrival interface will be added to that PIT entry's RequestFaces list, and the Interest packet will be discarded. This means that an Interest packet has already been sent upstream regarding this Data, so all is required is to ensure that whenever the correspondent Data packet arrives, it is also sent through the newly added interface to the inter face list.
- If there was no match in the PIT, a match is done for an entry in the FIB. In case of a positive match, the Interest needs to be sent upstream. The arrival interface is

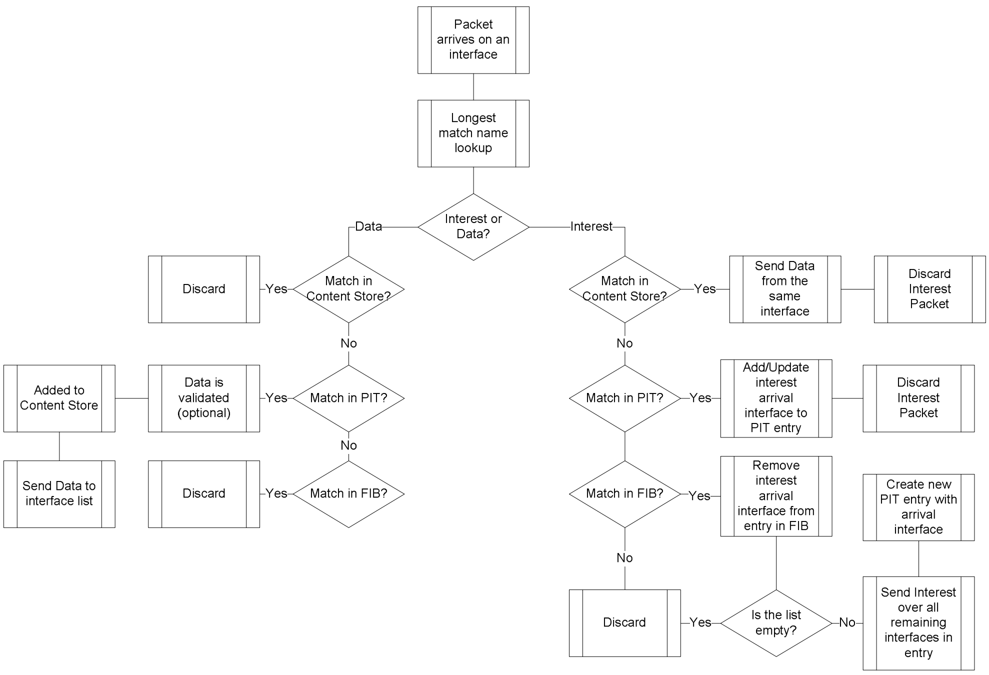

Fig. 3. CCN forwarding engine model state machine

removed from the face list of the FIB entry and, if there are remaining interfaces, the Interest is sent out all the interfaces that remain, while a new PIT entry is created.

- If there is no match in any of the data structures, then the node does not know about the Data or how to get it, and the Interest packet is discarded.

In case of a **Data** packet the procedure is the same, but the purpose now is to have it correctly forwarded through the directions provided by the PIT entries of each subsequent hop:

- If there is a Content Store match it means that the Data packet is a duplicate, so it is discarded.
- If there is a PIT match, it means the Data was solicited by Interests sent by this node. Optionally, this Data can be validated but then it is added to the Content Store. Then, a list is created by joining to the interface list of the matching PIT entries for this Data, minus the interface where the Data came from. The Data packet is then sent out through all the remaining interfaces of the list.
- If there is a FIB match it means that there are no matching PIT entries so the Data is unsolicited and it is discarded. This prevents, for example, malicious behavior.

This behavior, for both the Interest and Data packets allows nodes to be regarded as caching nodes throughout the network. Through the usage of this cache, a mobile node may serve as the network medium between disconnected areas. Contrary to TCP, CCN operation is stateless and thus reliability is achieved through resending Interest packets. Regarding duplication, as was seen in the previous flow chart, Data packets are always discarded in this case. As for Interest packets, the Nounce value contained therein is used to verify if there are similar Interest packets reaching nodes through different interfaces and, in that case, it they get discarded. Under these terms, flow balance is maintained in a hop-by-hop level.

B. CCN Naming

The Content Name portion of CCN packets are a very important part of the basic operation of the CCN architecture particularly because they are at the core of the sequencing of Data packets. These names are of a hierarchical nature, allowing nodes to do a prefix match for equivalence between requested data and possessed data, by saying that the Data packet is in the name sub-tree specified by the Interest packet. Furthermore, names in CCN are composed by a number of components and each one is composed of a number of arbitrary octets that have no meaning to the CCN transport. In fact, the meaning for these components is largely due to high-layer requirements or human readability. In fact, adopted conventions can be used to apply versioning and segmentation directly on the content's name, allowing requesters to request and identify different Data packets that form different parts of the same content. For example, the name of a content can include a version marker as well as a segment marker, enabling requesters to query for specific versions, or segments, of the same content (i.e., useful for ensuring reliability.

This querying mechanism allows specific requests, such as searching for the *leftmostchild* or *rightmostchildSibling* in large name sub-trees, allowing for efficient expression of what the receiver requires next. [3] states that the details of the query options are still under development and should be published at a future date.

C. CCN Mobility and Strategy

CCN does not share the IP restriction of forwarding on spanning trees, so it is able to take advantage of multiple interfaces (CCN packets cannot loop) or adapt to the changes produced by rapid mobility (i.e., there is no need to bind a layer 3 address into a layer 2 address). As stated in [3] "Even when connectivity is rapidly changing, CCN can always exchange data as soon as it is physically possible to do so". But, if the tools available to nodes that engage in mobility resume themselves to just sending a new Interest packet from the new location, seamless mobility is not necessarily guaranteed.

CCN provides some degree of configurability regarding the usage of multiple interfaces, through the addition of a set of policies to each CCN FIB entry. The purpose of these policies, a small program written for an abstract machine specialized for forwarding choices, is to determine how to forward Interests. By default, CCN uses a '*send an Interest on all Broadcast Capable Interfaces*' approach. These programs contain load/store, arithmetic and comparison mechanisms, as well as actions that operate on lists of interfaces (i.e., *sendToAll, sendToBest, markAsBest*, etc.) and triggers (i.e., *interestSatisfied, interestTimeOut*, etc.). Finally, each interface also contains a set of parameters (i.e., *BroadcastCapable, isCOntentRouter*) that can be used for the dynamic construction of interface sets.

The set of actions, triggers and parameters are called the CCN Strategy Layer and the program at the FIB is called the strategy to obtain the Data associated with the FIB's prefix.

The Strategy layer thus presents itself as a core part to enable 'tweaking' of the CCN inner-workings, particularly considering the prime manifestation of mobility in terms of vanilla-CCN behavior (i.e., the sets of interfaces).

D. Other CCN characteristics

At a glance, the information oriented flooding model of CCN along with a robust information security model, allows CCN to be mapped into any routing scheme that is mappable into IP. For example, both use prefix-based longest match lookups to find local neighbors that are closer to the identifier matched. An example provided in [3] provides insightful application of the CCN forwarding model and its attachment to existing IS-IS or OSPF networks, with no modification to it or its routers. A behavioral difference between CCN and IP that has to be considered regards multiple announcements of the same prefix. When this happens in IP, since it has no means to detect loops at content level, it then has to send all matching traffic to exactly one of the announcers. In CCN, this behavior does not occur because CCN packets cannot loop and thus all nodes send all matching interests to all of the announcers and a prefix announcement does not have to mean that the node is adjacent to all the content covered by the prefix.

Another issue revolving around inter-domain routing is when there are two domains that support CCN, interconnected by an ISP that does not support it: there is no way to learn of the relevant content router in the two different networks. The solution to this problem relies in the integration of domain-level content prefixes into BGP.

CCN had much concerns regarding not only content availability but also in the insurance of its validity. Contrary to IP, where clients have to fetch content directly from the source in order to trust it, CCN embodies security in the content itself. This is achieved with the authentication of the binding between names and content, where the signature in each CCN data packet is made over the name, the content and some support data for signature verification. Also, the fact that CCN packet signatures are standard public key signatures allows every of CCN node to be able to verify the name-content binding. The signature algorithm is chosen by the content publisher, enabling it to meet the performance requirements of that data. On its turn, each CCN Data packet contains enough information that enables the retrieval of the necessary public key for its verification. CCN also allows for some interesting possibilities, since content can securely link or refer other content, which means that we can have content certifying content and, in turn, allows for a small number of keys to be used in a large quantity of related content.

III. MULTIMEDIA APPLICATIONS FOR CCN

The CCN architecture, with its simplicity and flexibility, allows for the mapping of multimedia protocols and behavior such as Voice Over IP (VoIP). Here this mapping, called Voice over CCN (VoCCN) [4] encapsulates standard VoIP protocols (SIP, SRTP) having in mind future interoperability with unmodified VoIP implementations.

In order to obtain the desired VoIP behavior, some requirements are placed into CCN to achieve VoCCN. A primary requirement, taking into consideration the naming architecture and the CCN Interest/Data packets explained in the previous section, is the need to request content that has not yet been published. For example, in normal VoIP behavior, a destination IP address and port is established, and then newly created packets are sent there. However, due to the underlying architecture of CCN, a Data packet is never sent towards a consumer without first having the consumer explicitly requesting it via an Interest packet. So, not only there must be a way for requesting data that hasn't been created yet (i.e., the next piece of voice in a voice conversation) but it is also required that those requests are routed to potential publishers, and allowing them to create and then publish the desired content in response.

For this, VoCCN takes advantage of CCN's content structure where each fragment of content has a hierarchically structured name, which provides a simple way to request sequential Data packets once the initial naming has been established. Thus, CCN does not require that data be published and registered in CCN nodes before it can be retrieved. In fact, constructible names are another requirement for VoCCN since it has to be possible to construct the name of a desired piece of content a priori, without having the need to know that name previously or seen the content. For this, the authors of [4] intend to develop a deterministic algorithm by which the data provider and consumer arrive at the same name based on data available to both. In this way, names will not depend on data not available to both (such as cryptographic information required for the CCN security features).

Also, CCN allows pipelining by sending Interest packets for multiple future media packets to counter for delayed reception of media packets in dispersed or high-latency networks.

Lastly, the usage of CCN and its underlying features introduces some advantages over the normal functioning of VoIP. For example, the support of multipoint routing, which allows the automatic routing of a call request to all likely places where it might be answered. Also, inherent security features from CCN are here applied as well, enabling for secure voice communication.

In [4] a performance test was done, using a modified version of Linphone which had CCN behavior implemented, demonstrating that the performance is comparable to the normal VoIP version, except for some VoCCN packets (less than 0.1%) being dropped by Linphone due to late arrival.

Even though that the performance is on par with normal VoIP, and VoCCN has the added benefit of having intrinsic security mechanisms, the authors of [4] did not consider moving nodes in wireless environments, which seriously would impact results.

IV. PREDICTIVE MOBILITY OPTIMIZATION DESIGN

Having considered the features provided by CCN, an instantiation of a clean-slate Future Internet approach, one has to wonder about its deployability in more demanding mobility scenarios. The considerations on concepts of CCNs and VoCCN will be severely stressed under environments where users are mobile and use terminals which support multiple technologies (and thus creating different reception, routing and QoE requirements). This is the specific area and scenarios which this document expands.

Concretely, our visions explores scenarios where seamless mobility has to be aided by predictive mechanisms that inform the network about newly detected

Points of Attachement (PoAs), enabling network decision points to initiate reservations or other required actions to maintain traffic conditions. Exploring the basic CCN functionality, this will support efficiently mobility situations, including handovers.

Considering projects such as [2], multimedia sources in the future will no longer be regarded as fixed servers stationed at an operator's core, but can be mobile or even the users' terminals themselves. This is also covered in our approach. The design ideas below can be introduced into the fabric of CCN, augmenting it with the required mechanisms to support stringent seamless mobility scenarios. These design ideas are discussed in the next sub-sections, and can be structured as interest delegation, effective mobility strategy implementations, and content-aware mobility. These ideas can be implemented cumulatively or independently according to the mobility scenarios required to be supported.

A. Delegated Interests

The Delegated Interests concept considers the possibility of having other CCN-supporting nodes sending Interests on behalf of the requester. These nodes need to:

a) be on the path to the Content Source and

b) are part of the connectivity infra-structure (i.e., routers or even other terminals in case of ad-hoc and sensor networks)

Through the usage of link event triggers (for instance IEEE802.21 [5], used as described in [10]) the user's terminal (or mobility decision node belonging to the network), could instruct the next PoA to send a Delegated Interest on behalf of the original node, soliciting sending the content to this new locations. This would provide the construction of an Interest path to where Data packets could flow prior to the handover taking execution, allowing for seamless handover provision.

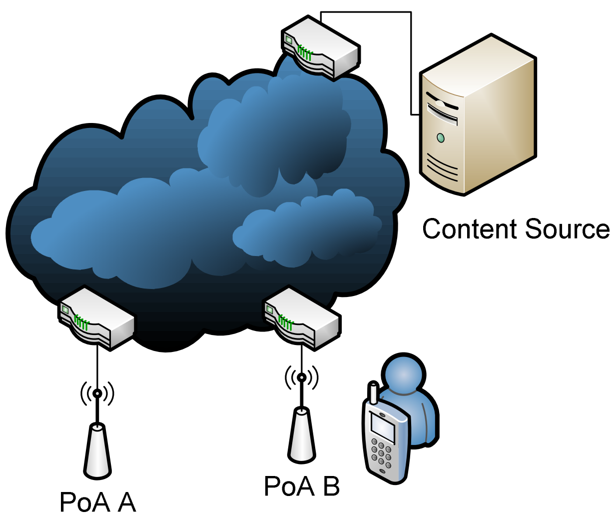

Figure 4. Delegated CCN Interest for Seamless Mobility

Several aspects need to be thoroughly explored, other than implementation of this mechanism and its performance evaluation, both related to CCN specifics as well as characteristics of the new behavior. For instance, it is required to develop a way for having an interface between the generation of these events and the CCN fabric. Another important factor if having the Interest being sent by a PoA on behalf of the node being correctly interpreted as a Delegated Interest (which has to contemplate the node as the final destination, and not just the PoA) from other normal Interests.

B. Mobility program/abstract machine for forwarding options (strategy layer)

This explores the concept of the CCN's strategy layer at CCN nodes and their ability for some configuration regarding the usage of multiple interfaces. In this case, the mobility aspect is more considered in mobile terminal mobility management, because it addresses the management of Interest packets by the different interfaces available at a terminal. In this case, the default CCN behavior of sending Interest packets on all Broadcast capable interfaces is replaced by providing awareness of the network surroundings of the node to the Strategy Layer. This would enable it to send Interest packets from the interface which would be the final attachment point after a handover.

This behavior poses some important implementation issues to be resolved, such as what to do when the other interface is not yet active, and how to execute this behavior in a predictive way in order to provide a seamless handover.Also, some thought must be placed on solving the inherent mobile terminal management of this approach: this could be coupled with the solution provided by the previous sub-section, enabling mobile terminals to indicate to the network mobility decision nodes their handover intent. In this manner, the strategy layer would not work by configuring the way Interest packets left the terminal, but the other way around, by configuring how Data packets leave the source.

C. Content-defined mobility

This approach considers both the source and the mobile terminal point of view regarding mobility. In this approach, the Interest and Data packets would possess mobility-related information that could be used to dynamically adjust previously created Interest paths, according to the mobility of user nodes. This could be achieved for both network-operated (i.e., via change of the Data packets) as well as for terminal-operated (i.e., via change of the Interest packets) mobility. This approach, albeit much more powerful, would require much more complex CCN nodes, and as such would only seem required in very stringent scenarios.

V. CONCLUSIONS AND FUTURE WORK

This document provided a brief introduction to the CCN architecture while highlighting some issues and possible inadequacies concerning seamless mobility in wireless environments by moving terminals. Based on that, we then presented three new possible solutions for having CCN as a full fledged solution under those environments.

However, analysis of the CCN design by interpretation of the architecture description in [3] and its adaptation to multimedia environments [4] is not enough to actually prove that CCN does not perform well in seamless mobility scenarios. For that, actual experimentation needs to be done using [6] and compare it to IP approaches in the conditions of seamless mobility scenarios.

After this, further development of the three key concepts needs to be done, in order to determine the best approach that performs in all the identified situations (i.e., seamless mobility, static or moving content, wireless technologies and performance, etc.). This can be achieved by further designing the concepts and elaborating simulations for performance comparison, enabling us to choose the best approach, or to even identify specific particularities of each approach that can be coupled into a single method for optimized seamless mobility. For example, the mechanisms for link layer events provided by IEEE802.21 can easily be adapted to the other key ideas and enhance their behavior. Also, an important factor is to insure that the final design considers mobility of not a single user, but of many (and, of course, consider large scale deployability in the Internet) since an important consideration of CCN is its multi-source ability, contrary to normal IP behavior).

REFERENCES

[1] Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update", Cisco White Paper [Online]. Available: http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/whitepaper c11-520862.html

[2] FP7 EU project: MultimEDia transport for mobIlE Video AppLications (MEDIEVAL), Grant agreement no. 258053.

[3] Jacobson, V.; Smetters, D. K.; Thornton, J. D.; Plass, M. F.; Briggs, N.; Braynard, R. "Networking named content". Proceedings of the 5th ACM International Conference on Emerging Networking Experiments and Technologies (CoNEXT 2009); 2009 December 1-4; Rome, Italy. NY: ACM; 2009; 1-12.

[4] Jacobson, V.; Smetters, D. K.; Briggs, N.; Plass, M. F.; Stewart, P.; Thornton, J. D.; Braynard, R. "VoCCN: voice over content-centric networks". Proceedings of the 2009 Workshop on Re-architecting the Internet (ReArch 2009); 2009 December 1; Rome, Italy. NY: ACM; 2009; 1-6.

[5] IEEE 802.21 Standard, "Local and Metropolitan Area Networks – Part 21: Media Independent Handover Services", January 2009.

[6] Project CCNx, http://www.ccnx.org/ , July 2010

[7] Named Data Networking (NDN) Project, NDN-0001, http://www.named-data.net/ndn-proj.pdf, October 31, 2010.

[8] Ma, K.J.; Bartos, R.; Bhatia, S.; Nair, R.., "Mobile video delivery with HTTP", IEEE Communications Magazine, April 2011 Volume : 49 , Issue:4, pp. 166 – 175.

[9] Ramzan, N.; Quacchio, E.; Zgaljic, T.; Asioli, S.; Celetto, L.; Izquierdo, E.; Rovati, F.; "Peer-to-peer streaming of scalable video in future Internet applications", IEEE Communications Magazine, Volume: 49 , Issue: 3, 2011 , pp: 128 – 135.

[10] Daniel Corujo, Bruno Santos, Carlos Guimarães, Rui L. Aguiar, "Using an Open-Source IEEE 802.21 Implementation for Network Based Localized Mobility Management", IEEE Communications Magazine, vol 9, pp. 114-123, September 2011.