Managing availability in wireless inter domain access

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***Abstract*—This paper deals with how the availability of wireless/cellular access networks depend on the cooperation between the operators as well as with transmission network operators and professional land lords. The forthcoming 4G network will consist of diverse sets of wireless/cellular networks integrated into IP-based networks. Mobility, QoS and seamless handover between the networks are key features. In [1] the concept of Always Best Connected is defined as means that the user is connected through the best available device and access technology at all times. Availability of the access is fundamental for QoS and critical services (e.g. emergency services, health services) are more and more dependent of wireless/mobile access. Availability can be increased by utilization of several accesses through seamless handover and/or multihoming. Usually, the availability has been calculated assuming independencies between the access network operators, but in this paper we show that the actual cooperation between the market actors has significant impact on the availability. We propose a solution by usage of the IMH 802.21 framework to build and distribute network topology information with availability estimates allowing to predict the overall availability for the access networks accessible as one of the criteria for a handover decision.**

I. Introduction

The wireless access (packet based) to Internet was standardized by IEEE with the 802.11b protocol and for cellular environment by ETSI with GPRS in 1999, with start of deployments in 2000/2001. Later both wireless as well as cellular environments have enhanced functionality/QoS with WiMAX and UMTS/LTE respectively. The traditional cellular phone has become a multi purpose equipment capable of multiple access technologies with open operating systems supporting third party applications and the difference between such a terminal and a PC is not obvious any more.

In this paper we consider how to manage availability of the network access where the user can use different access technologies from one or several operators. Availability of the access is fundamental for QoS and critical services (e.g. emergency services, health services) are more an more dependent of wireless/mobile access. Each access network provides a certain availability for access at the location in concern. With usage of user equipment capable of utilizing several access technologies, either simultaneously or one access at any given time, the availability of the access will

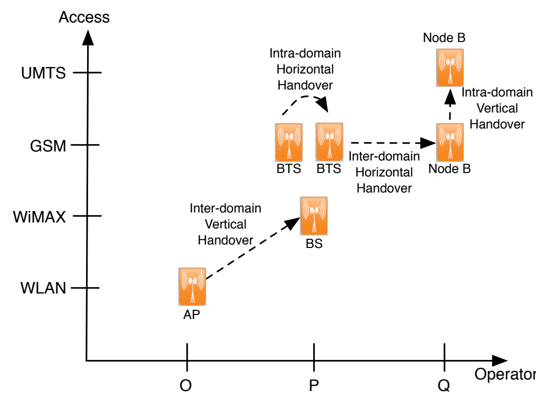

Fig. 1. Handover and multihoming for a given location.

be increased. Both multihoming (simultaneously access) [2] and handover requires mechanisms in the user equipment and network to ensure seamless service continuity. Such mechanisms are outside the scope of this paper. Figure 1 gives an example of possible accesses the user equipment can utilize at a certain location. Vertical handover is the term used to change the point of attachment from one access technology (e.g. GSM) to one another (e.g. UMTS). Horizontal handover is the term for a change of point of attachment within the same access technology (e.g from GSM to GSM). If the point of attachment is within the same operator, it is an intra-domain handover, otherwise it is a inter-domain handover. Multihoming can also be used and in this scheme a handover is more the execution of moving from the primary path to one of the secondary paths. The availability predictions can be used as one of the criteria for handover execution to ensure service continuity.
Analytical and simulation methods for dependability analysis for repairable computer/network systems have been an active area of research for a long time, see e.g [3], [4] and Chu [5]. Han et al. [6] performed an experimental measurement-based analysis (usage of trace route and routing tables) of the Internet path diversity, focusing on the impact of path diversity on multi-homed and overlay networks. A background for this study was that the Internet routing infrastructure is

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highly fault tolerant and that paths traversing different ISPs (or overlay nodes) would enjoy a high degree of diversity. The study showed that multi-homing route control or current overlay network did not ensure path diversity. In Yannuzz et al. [7] the challenge of inter domain routing between ASs is described based on BGP where load sharing and multi-homing are the main reasons for the BGP tables to grow so fast and that this again slows/prevents the actual usage of the redundancy. For critical infrastructure (national electrical grid, oil and gas system, telecommunication networks, transportation networks etc) there is related research, see e.g. [8] and [9]. However, these are focused on regional and nation wide concern related to large scale natural disasters and coordinated acts of terrorism.

In this paper we will describe how the availability of wireless/cellular access networks are dependent on the cooperation between the market actors. The novelty of this paper is the real time calculation of availability prediction for a user at a given location by usage of the IMH framework. We consider a given location where the user have coverage from three different access technologies, WLAN, WiMAX and UMTS. The availability for the wireless links are important, and will be treated separately and is not dealt with in this paper.

The rest of the paper is organized as follows. Section two gives information of market trends in deployment and operation of access networks. In section three a possible deployment scenario with three operators each providing WLAN, WiMAX GSM and UMTS respectively are described. Section four describes the proposes model. In section five we conclude this paper.

II. Market trends in deployment and operation

A. Cooperations in general

The usage of wireless/celluar access has become important both for business as well as for the social communities, infotainment and gaming. The expectations for access with any device at any time anywhere to any application/information are now taken for granted. Such expectations put a lot of requirements and generates complexity for the standardization bodies/forums, operators and service/content providers. In [1] the concept of Always Best Connected is defined as means that the user is connected through the best available device and access technology at all times. This definition covers aspect such as e.g. personal preferences, size and capabilities of the device, application requirements, security, operator or corporate policies, available network resources and network coverage. The market actors, such as network operators, service providers or content providers, ultimate goal are to earn money for the stake holders. For the operators it is a huge challenge to balance the cost vs. benefits both in short and long term. The traditional cooperation between network operators based on site sharing and hiring leased line transmission is becoming by far more developed. Such cooperations include e.g.;

- building multi purpose network independent of actual traffic (e.g. signaling, user data).
- equipment/network sharing through e.g. virtualization.
- outsourcing of development and maintenance.

The complexity of performing a dependability analysis has increased with the increased dependencies between logical resources and networks operated by different operators that are combined in shared physical entities. A physical router might be divided into a number of virtual routers each used/operated by different operators, transmission media (cables/fibres) might be placed in the same ditch, the same power supply might be used to feed several network elements operated by different operators etc.

B. Wireless access networks

The interface between access and core network is constituted by the WLAN Controller, Access Service Node Gateway (ASN-GW), Base Station Controller (BSC) and (RNC) for WLAN, WiMAX, GSM and UMTS respectively. The WLAN Controller, ASN-GW, BSC and RNC (Access Controllers) are part of the access networks with interfaces to the core network as shown in Figure 2. The different accesses have very similar network architectures, with one or several wireless access points connected to a controller. The Access Controllers for the different access networks perform several similar functions such as e.g. SW/config management, radio resources management, admission control, mobility, handover control, security and QoS for the access points (AP/BS/BTS/Node B) connected. The Access Controllers might use the measurements (e.g. signal strength, signal quality) from the user terminals to execute handovers and radio resource management. The Access Controllers can also be seen as a transmission concentrator for connections to the access points. Consider a location from where the user have coverage from four access technologies as shown in Figure 2. The access technologies are operated by three different access network operators. In

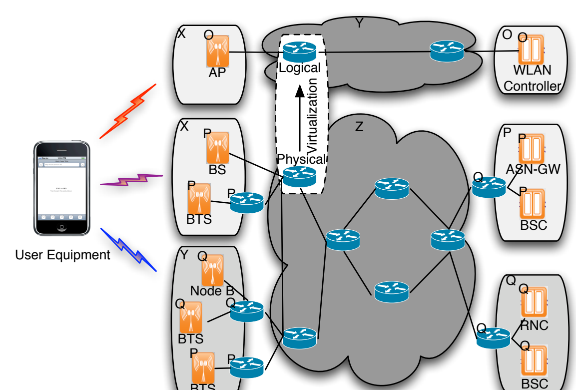

Fig. 2. WLAN, WiMAX, GSM and UMTS Network sharing.

the figure the access network operators are denoted O, P and Q. Assume that the user has a terminal that supports these access technologies and that the applications/services that it uses ensure a seamless vertical and horizontal as well as inter- and intra domain handover. In the figure the operator owning the equipment is given by the identifier in the upper left corner of the equipment. For the transmission the named cloud surrounding the equipment is the owning operator. The owner of the sites, is shown with the identifier in upper left corner of the squashed rectangles.The black and white genres of the surrounding squashed rectangles or clouds indicates different maintenance and repair organizations.

Furthermore, assume that the network access operators are using leased transmission from a transmission network operator, denoted Y and Z in the figure. It is possible that a transmission network operator, as operator Y, has leased a virtual equipment from transmission operator Z. Usage of leasing may be encouraged by timing and cost. With leasing existing infrastructure, there will be less time needed to establish the connections needed since the acquisition of sites/ditches are already in place. By regulation some operators having a strong marked position are regulated to provide leasing agreements. The usage of leased transmission from a regulated transmission network operators or under normal unregulated market conditions should be attractive, as this may be at lower cost and with better timing than achievable with own infrastructure.

Let say the access network operator lease the site from professional land lords, denoted X and Y in the figure. The land lords may also require that the access network operators lease power and cooling, since a common power infrastructure (AC/DC with possible diesel aggregates) and cooling is most efficient if common room(s) is used for the access network operators.

III. Case Scenario

A. Overview

Figure 3 gives an overview of the case used for illustration of the availability effected. The transmission network operator has divided the transmission network into two main parts; the metropolitan and the regional part. In this scenario, the leased transmission is Ethernet. Due to the need for synchronization and pseudo-wire emulation between the RNC and Node B, operator Q has deployed necessary equipment at RNC site and Node B. The transmission network (metro and regional) is expected to have fault tolerant and network recovery mechanisms deployed. The regional part might have a higher fault tolerant solution than the metro part. Similarly, both the power and cooling are expected to be fault tolerant (e.g. using A and B power with battery backup). We assume that the access network operators are buying the same product from the transmission network operator and the land lord, i.e. they have the same SLA (regulated e.g. the availability terms). The operators perform the maintenance and repair on their own equipment.

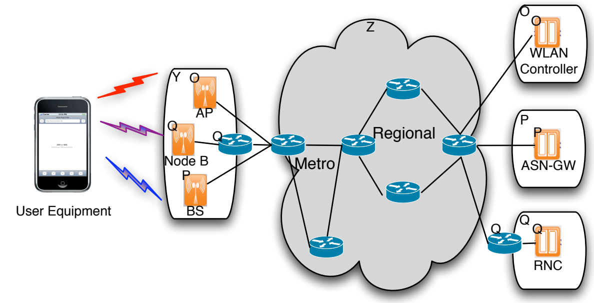

Fig. 3. A dependent access scenario.

B. Availability calculations

The most common availability measure is the asymptotic availability, denoted A. This assumes that the system in concern have reached its steady state, and A gives the probability of finding the system in a working state at a random time. There is a well known relationship between the Mean Up Time (MUT) and Mean Down time (MDT) and Mean Time Between Failures (MTBF) under stationary conditions. MUT^{-1} is equal to the failure intensity λ for the system in concern.

$$A = \frac{\text{MUT}}{\text{MDT} + \text{MUT}} = \frac{\text{MUT}}{\text{MTBF}} = \frac{1/\lambda}{\text{MDT} + 1/\lambda} \quad (1)$$

Traditionally calculations of the overall availability for the access networks for the critical service would assume independently failures between the access networks. Let A_i be the availability of the equipment specific for technology $i \in \theta$, where $\theta = \{WLAN, WiMAX, UMTS\}$. Taking into account the availability of the other elements, the metro transmission (A_{met}), regional transmission (A_{reg}) and power (A_{power}) and cooling ($A_{cooling}$) at the BS/AP/Node B sites, the availability prediction from a multi access technology user assuming independence becomes;

$$\hat{A}_{tot} = 1 - \prod_{i \in \theta}(1 - A_i A_{met} A_{reg} A_{power} A_{cooling}) \quad (2)$$

Since the transmission is leased from the same transmission network operator, the overall availability of the transmission network and common infrastructure at the BS/AP/Node B site are no longer independent between the access networks. The correct availability equation prediction should be;

$$A_{tot} = (1 - \prod_{i \in \theta}(1 - A_i)) A_{met} A_{reg} A_{power} A_{cooling} \quad (3)$$

The common infrastructure and transmission lines have a fundamental effect on the overall availability as seen with (3) compared with (2). The common factor $A_{met} A_{reg} A_{power} A_{cooling}$ is independent of the number of access systems and dominates the availability. This may be illustrated by Figure 4, assuming that all the availability estimates except A_{met} are 0.99 and varies the A_{met} between 0.80 and 0.99. As shown, $\hat{A}_{tot}$ is over estimating the availability.

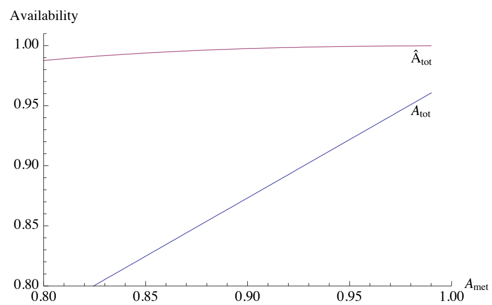

Fig. 4. Availability with varying A_{met} and the other estimates set to 0.99.

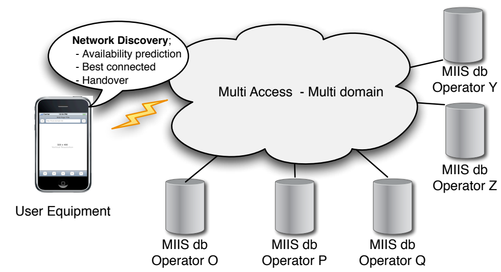

Fig. 5. Network Discovery through IMH framweork.

IV. Proposed model

A. Network topology

For availability predictions the insight into of the underlaying structure of the system is required. In an inter domain environment the network structure and interaction as well as dependencies between the domain are very complex. Taesombut [10] evaluates the network information models on resource efficiency and application performance in lambda-grids in multi domain environment. The key finding is that the domain topology information is crucial for achieving good resource efficiency. However, there are some concerns regarding the operators willingness to share such information of their internal resources based on;

1) Security
2) Financial benefits
3) Internal network management
4) Inter domain routing policy enforcement
5) Protocol heterogeneity

Taesombut assume that the such collaboration should be possible with a trustworthy third-party agent. We do believe that the same concerns are also valid for an information sharing concerning network topology and availability estimates. However, with increasing demands for QoS and trustworthiness of the system, more information has to be provided to the customers. For network access topology, the most fundamental is the coverage area. Some access network operators already provide coverage maps, accessible through their WWW home page, with the actual sites. The availability predictions for the access are already given for some business customers in the SLA. The availability estimates will most probably be given as aggregates for the network or parts of the network.

B. A topology and dependability aware MIIS

We propose a solution to the availability prediction challenge based upon Independent Media Handover (IMH) framework, IEEE 802.21 [11]. This may be used to obtain the network topology information with availability estimates together with coverage information.

The IMH enables a given network to discover and receive advertisements from other networks, and to request additional information. It defines a database, the Media Independent Information Services (MIIS) database, for discovery/querying of network information, mostly static, of the serving and neighbor networks, but has neither defined the actual implementation of this database nor how this is populated. The information is separated into three main categories, each defined with Information Elements;

1) Network Specific Information.
2) Point-of-Attachment Information.
3) Vendor specific information elements.

Moon et al. [12] have addressed the access network discovery for IMH, since access network discovery is undefined in the framework. In this paper it has been observed that the decentralized access network discovery with dynamic monitoring of access network based on the terminal moving speed may save user equipment consumption. Monitoring of fewer access network has benefit in power consumption but may degrade the QoS. To ensure service continuity we propose to use the availability prediction for the access networks as one criteria for network selection and to perform handover execution.

C. Population of MIIS database

To populate the MIIS database we propose a solution where the infrastructure providers (access network operators, transmission network operators etc.) push the network topology data with corresponding availability estimates to their MIIS database. To obtain the complete network topology for a certain location, it might therefore be necessary to use information from several operator MIIS databases. Access network topology, with necessary availability estimates, should be possible to obtain from the Operations Support Systems (OSS) used by the infrastructure providers. The infrastructure providers use OSS to configure the network/infrastructure, for monitoring and maintenance and for optimization. An infrastructure provider may have several OSS for different parts of the network/infrastructure. In Figure 5, the operators described in subsection III-A have their own MIIS database. The user terminal will access the MIIS database belonging to the access network operator for the point of attachement (i.e. operator A, B or C). The information obtained from the MIIS databases is for network discovery and to select the best point of attachment based on e.g. availability prediction.

TABLE I
NEW INFORMATION ELEMENT IE_POA_STRUCT

Information element	Description	Data type
IE_POA_STRUCT	system function expressed in a minimal product-of-sums form.	STRUCT_INFO

D. MIIS database Information

Since the infrastructure providers are leasing/sharing infrastructure, the MIIS database must be able to identify such shared resources. To be able to reflect the actual dependencies between the infrastructure providers, we propose to use the identifier of the resource prefixed with the owner of the resource. In this way we avoid possible duplications of resource identifiers. For instance, if operator O is leasing a transmission from operator Y from site A to site B, this is identified by a element identifier, which is unique within operator Y. Operator O has the knowledge of the ingress and egress, while the operator Y has the knowledge of the resources used between ingress and egress, though it is possible that operator Y lease resources/lines from operator Z. The same identification mechanism is used for all resources such as network elements, virtualization of routers, ditches/cables, infrastructure (power, cooling), etc. The actual access network topology of an infrastructure provider might be aggregated as long as the aggregate only consist of its own resources and independent of egress and ingress (e.g must be independent on elements included). For instance, for an UMTS access network operator the RNC site having central synchronization equipment used for Ethernet transmission to Node B is aggregated into one resource with associated availability estimates, see Figure 3. Aggregates can only be used as long as the aggregate represent a building block that is independent of the operator leasing capacity. An example of such independency can be metro transmission rings, where the ring is independent of the actual site connected or leasing operator.

We propose to include the availability estimates for the access network in the Point of Attachment (PoA) specific information, i.e. in the IE_Container_PoA of [11]. This gives the possibility to provide different availability estimates for each PoA, i.e. BS/AP/Node B. The new information element IE_POA_STRUCT, see Table I, provides information to define a structure function expressed in minimal product-of-sum of the SYS_ID (Table II) contained. The structure function is a logical function that expresses whether the system is working or not. The product-of-sum structure provides a concise way of expressing the structure function without explicit need for operators. A minimal sum-of-products is a irreducible boolean sum (logical OR, $\vee$) of minterms, where a minterm is a boolean product (logical AND, $\wedge$) that may include a variable only once. Each of the maxterm of the structure function expressed in a minimal sum-of-products corresponds to a minimal cut set.

Each of the SYS_ID has an estimated availability attached,

TABLE II
NEW TYPE

Type name	Derived From	Definition
STRUCT_INFO	LIST(CUT_SET)	A type for structure
CUT_SET	LIST(SUB_SYS)	A type for maxterm
SUB_SYS	SEQUENCE(SYS_ID SYS_AVA CHOICE(SYS_FAIL_INT, NULL))	A type for availability for each sub system
SYS_ID	SEQUENCE(OPERATOR_ID OP_SUBSYS)	A Type for operator subsystem id
OP_SUBSYS	OCTET_STRING	Subsystem id
SYS_AVA	OCTET_STRING	Availability
SYS_FAIL_INT	OCTET_STRING	Failure intensity year

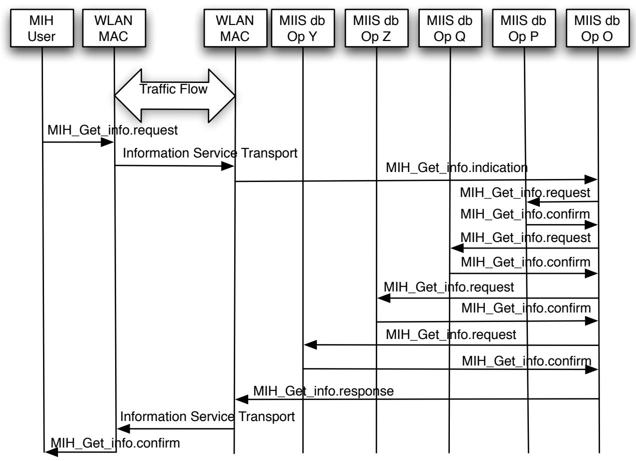

Fig. 6. Availability estimates obtained through IMH framework.

the SYS_AVA (Table II). The SYS_AVA is used to combine the availability predictions for the PoA from the structure function for the PoA. Since the SYS_ID is unique, a system structure for all accesses seen by the user can be constructed, also in expressed in minimal product-of-sum. From this the availability prediction for all access networks can be derived.

E. Availability calculation based on MIIS

Consider the same scenario as defined in section III. Assume that a IMH user, could be an application/service deciding when to execute a handover, request the IMH for information of the available networks, as well as the availability estimates through the IE_POA_STRUCT information element. Figure 6 shows how the IMH framework uses the existing established link to obtain the necessary information from the MIIS databases. From the location information in the request message, the MIIS can derive the available PoA. In this example, there exists several MIIS databases with the necessary information. The obtained information can be used by the IMH user to predict the availability for each access

TABLE III
EXAMPLE USED FOR SUB_SYS IN SHARED SCENARIO

Definition	Value	Description
SUB_SYS	(O w30, 99, 1.0)	Operator O, AP WLAN #30
SUB_SYS	(O c1, 999, 0.1)	Operator O, WiF controller #1
SUB_SYS	(P w10, 99, 1.0)	Operator P, WiMAX BS #10
SUB_SYS	(P g2, 999, 0.1)	Operator P, ASN-GW #2
SUB_SYS	(Q u89, 995, 0.5)	Operator Q, Node B (w/router) #89
SUB_SYS	(Q c4, 9999, 0.01)	Operator Q, RNC (w/router) #4
SUB_SYS	(Y p1, 999, 0.1)	Operator Y, Power #1
SUB_SYS	(Y c7, 999, 0.1)	Operator Y, Cooling #1
SUB_SYS	(Z m9, 99, 1.0)	Operator Z, Metro #9
SUB_SYS	(Z r2, 999, 0.1)	Operator Z, Regional #2

as well for the overall availability. The failure intensity is an optional type, see definition of SUB_SYS (Table II). Assume that the elements have the identities as given in Table III. The system structure function for each access, in minimal product-of-sum, is constructed as;

$$\phi(\text{wlan}) = O_{w30} \wedge O_{c1} \wedge Z_{r2} \wedge Z_{m9} \wedge Y_{p1} \wedge Y_{c7} \quad (4)$$

$$\phi(\text{wimax}) = P_{w10} \wedge P_{g2} \wedge Z_{r2} \wedge Z_{m9} \wedge Y_{p1} \wedge Y_{c7} \quad (5)$$

$$\phi(\text{umts}) = Q_{u89} \wedge Q_{c4} \wedge Z_{r2} \wedge Z_{m9} \wedge Y_{p1} \wedge Y_{c7} \quad (6)$$

The dependencies between the access networks are identified by the common values of the SYS_ID in the system structure functions. The system structure function all accesses are $\phi(tot) = \phi(\text{wlan}) \vee \phi(\text{wimax}) \vee \phi(\text{umts})$, i.e. this yields;

$$\phi(\text{tot}) = (O_{w30} \wedge O_{c1} \vee P_{w10} \wedge P_{g2} \vee Q_{u89} \wedge Q_{c4}) \wedge Z_{r2} \wedge Z_{m9} \wedge Y_{p1} \wedge Y_{c7} \quad (7)$$

Assume that the elements have the availability predictions as given in Table III. Let A_i be the availability of the equipment specific for technology $i \in \theta$, where $\theta = \{WLAN, WiMAX, UMTS\}$. The availability prediction for A_i is $A_{Ow30}A_{Oc1}$, $A_{Pw10}A_{Pg2}$ and $A_{Qu89}A_{Qc4}$ respectively. Taking into account the availability of the other elements, the availability prediction of all accesses can be derived from (7) and we get;

$$A_{tot} = (1 - \prod_{i \in \theta}(1 - A_i))A_{Zr2}A_{Zm9}A_{Yp1}A_{Yc7} \quad (8)$$

The structure of (8) identical to structure given in (3). A minimal product-of-sum of $\phi(tot)$ given in (7) is;

$$\begin{aligned}\phi(tot) = {} & (O_{c1} \vee P_{g2} \vee Q_{c4}) \wedge (O_{c1} \vee P_{g2} \vee Q_{u89}) \\ & \wedge (O_{c1} \vee P_{w10} \vee Q_{c4}) \wedge (O_{c1} \vee P_{w10} \vee Q_{u89}) \\ & \wedge (O_{w30} \vee P_{g2} \vee Q_{c4}) \wedge (O_{w30} \vee P_{g2} \vee Q_{u89}) \\ & \wedge (O_{w30} \vee P_{w10} \vee Q_{c4}) \wedge (O_{w30} \vee P_{w10} \vee Q_{u89}) \\ & \wedge Z_{r2} \wedge Z_{m9} \wedge Y_{p1} \wedge Y_{c7} \quad (9)\end{aligned}$$

As shown with (9) the minimal product-of-sum can be significantly reduced with boolean operations and we can get the expression given by (7). To predict the availability from a structure function where one or more elements are represented more than only once in the structure function, the inclusion-exclusion method can be used as described in [13] to successive bound the system availability.

V. CONCLUSION

Based upon the IMH framework we have proposed how to model the inter dependencies between access network operators. The MIIS database is proposed populated with information from the OSS used by the access network providers. A IMH user can request from information from the MIIS database to gather information of interdependencies between the accesses and the availability estimates for the subsystems. New information element and data types are proposed to describe the dependencies in terms of cut sets. The usage of cut sets has limitation since it assumes independencies in failures as well as restoration of the subsystems. We will further investigate the proposed model for how to include the wireless links, failure intensity and dependencies in failures and restoration. As long as there is limited resources or when the maintenance is outsourced to a third party, there exists dependencies in restoration between subsystems.

REFERENCES

[1] E. Gustafsson and A. Jonsson, “Always best connected,” *IEEE Wireless Communications*, vol. 10, no. 1, pp. 49–55, Feb. 2003.

[2] K. Kim, S. Min, and Y. Han, “Fast handover method for mSCTP using FMIPv6,” *Lecture notes in computer science*, vol. 3794, p. 846, 2005.

[3] S. Porcarelli, F. Di Giandomenico, A. Bondavalli, M. Barbera, and I. Mura, “Service-level availability estimation of GPRS,” *IEEE Transactions on Mobile Computing*, vol. 2, no. 3, pp. 233–247, July–Sept. 2003.

[4] H. Pant, C. Chu, S. Richman, A. Jrad, and G. O’Reilly, “Reliability of next-generation networks with a focus on IMS architecture,” *Bell Labs Technical Journal*, vol. 12, no. 4, 2008.

[5] C.-H. K. Chu, H. Pant, S. H. Richman, and P. Wu, “Enterprise VoIP reliability,” in *Proc. 12th International Telecommunications Network Strategy and Planning Symposium NETWORKS 2006*, 2006, pp. 1–6.

[6] J. Han, D. Watson, and F. Jahanian, “An experimental study of internet path diversity,” *IEEE Transactions on Dependable and Secure Computing*, vol. 3, no. 4, pp. 273–288, Oct.–Dec. 2006.

[7] M. Yannuzzi, X. Masip-Bruin, and O. Bonaventure, “Open issues in interdomain routing: a survey,” *IEEE Network*, vol. 19, no. 6, pp. 49–56, 2005.

[8] S. M. Rinaldi, “Modeling and simulating critical infrastructures and their interdependencies,” in *Proc. 37th Annual Hawaii International Conference on System Sciences*, 5–8 Jan. 2004, p. 8pp.

[9] N. Svendsen and S. Wolthusen, “Graph models of critical infrastructure interdependencies,” *Lecture Notes in Computer Science*, vol. 4543, p. 208, 2007.

[10] N. Taesombut and A. A. Chien, “Evaluating network information models on resource efficiency and application performance in lambda-grids,” in *SC ’07: Proceedings of the 2007 ACM/IEEE conference on Supercomputing*. New York, NY, USA: ACM, 2007, pp. 1–12.

[11] IEEE, *IEEE Std 802.21,D11 Draft Standard for Local and Metwropolitan Area Networks: Media Indepenedent Handover Services*, Std., 2008.

[12] C. Moon, S. Yang, and I. Yeom, “Performance analysis of decentralized RAN (radio access network) discovery schemes for IEEE 802.21,” in *Proc. VTC-2007 Fall Vehicular Technology Conference 2007 IEEE 66th*, 2007, pp. 41–45.

[13] R. Barlow, F. Proschan, and F. S. U. TALLAHASSEE, *Statistical theory of reliability and life testing: probability models*. Holt, Rinehart and Winston New York, 1975.