Analysis of Enhanced Access Selection Methods and End-User Perception in Multi-operator Environment

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Abstract

Nowadays, the access selection methods are done based on operator incentives using static and predefined rules. But once the number of deployed access technologies and mobile services is increasing, then today's access selection practices are not adequate anymore. We need to think about end-user preferences in a decision making process. Two new distributed decision making algorithms called the Network Centric and the Terminal Centric algorithms exploiting Ambient Networks mechanisms are presented. These algorithms use a richer set of constrains and rules. In order to evaluate these algorithms from an end-user perspective, we introduce a new performance index called the User Satisfaction Index. We present our simulation model, performance results and analysis. The results indicate that the cooperation between networks increases the network utilization and service availability. The benefits from an end-user perspective are expressed using the proposed User Satisfaction Index. Finally, we discuss on further challenges of a decision making for information centric networking.

KEYWORDS: Access selection algorithm, Network cooperation, User experience, User satisfaction index, Network composition

1. Introduction

The recent achievement in technology domain and in business concepts, have resulted large increase in the use of wireless broadband that can be observe today. For instance, deployment of High-Speed Downlink Packet Access (HSDPA) technology in the 3G networks has provided the basic capacity for large scale usage of mobile broadband. As an example from the prolong we mention, Wireless LAN (WLAN) access at hotspots, which have been available for many years at quite high cost, but nowadays they are offered at very low cost, for "free" or included in some service bundle. In general, the introduction of very attractive flat rate pricing for the mobile broadband access is one of the key reasons for the "mobile data explosion".

However, this large increase in traffic will put very high requirements on the availability of low cost high capacity wireless networks implying that additional capacity and investments are needed. While new radio access technologies like Long-Term Evolution (LTE) will contribute substantially to the needed reduction of network costs, mobile network operators will need to develop and consider new deployment and cooperation concepts for network sharing, roaming at a national and local level, reuse private networks and off-loading of traffic to low cost networks. Especially off-loading and exploitation of available accesses in a multi-access environment require more sophisticated access selection means in order to hide the extra complexity introduced by a diverse networking environment for the end-users.

In this paper we will discuss and analyze cooperation between different types of radio access networks and extend the simulation results presented in The Third International Conference on Systems and Networks Communications (ICSNC 2008) [1]. The cooperation between operators both result in lower network costs as well as increased network utilization and availability for the end-users when enhanced decision making is used.

Someone may ask *"what's new here?"*. Operator cooperation and use of multi-radio access technology have existed for many years. Many operators already use network sharing (e.g. based on [2]) and national roaming. Networks with different types of Radio Access Technologys (RATs) have also existed for many years. The principles of Multi-Radio Resource Management (MRRM) have been researched, designed and tested for many years and the performance gains are well known. Also interworking between 3G and WLAN systems [3] is standardized. So, it sounds that good justification is needed to make this topic relevant and *"new"*.

One part of the justification of extended network cooperation is related to service availability and coverage. Operators traditionally allow own customers to access their own network only. In case when the own network does not have coverage the own customer simply cannot connect to other available networks on the coverage. For international roaming the case is different, the user terminal switches to another operator networks as soon as the coverage is reduced for the current operator. In this sense visitors have better service availability due to the international roaming agreements. Hence, the type of cooperation we are proposing is more or less national roaming applied at a local and regional level [4] [5] [6]. In general the principle should be that "anyone" can connect to "any" network [7] [8] [9]. However, in this paper we assume that users have agreements (subscriptions) with some kind of service provider [5]. Typically this is a network operator but it could also be a virtual operator (without own access network resources), a service provider or a trusted third party, e.g. a credit card company.

Second part of the justification of increased cooperation is related to traffic, revenues and network costs. During the last two years there has been a very large increase of usage of mobile data using wide area networks, up to 300-500% . The data service problem for the operators is that although the traffic increases substantially, in contrast to the voices service (and charging per minute of use) where the revenues and traffic increase coherently, increase in the revenues is falling behind [10], due to dominating flat rate charging. The revenue per MB of data is around 1 euro for voice and 0,01 euro for "data" and for some operators the mobile data is 60-80% of the traffic but the corresponding revenues are only 10%.

The operators are challenged by what we can call a "revenue gap". Hence, the operators must focus a lot on cost control and deployment of "low cost" networks in order to meet the increased demand of mobile data services. The different types of cooperation mentioned above can all contribute to this cost reduction although it will not "solve" the whole problem. In addition to the possible cost savings a number of other aspects need to be considered and analyzed in order to both understand and exploit the possible benefits of cooperation:

- the structure and organization of a market with a multitude of network operators, service providers and different types of third parties and middlemen
- the impact on markets and competition due to the facts that end-users more freely can choose between many providers
- the types of business relations and agreements between providers
- the algorithms used for selection of network and radio access technology
- the potential improvements in network utilization and service availability
- the user experience of the increased service availability

The three first aspects have been discussed and analyzed in both public deliverables [4] [11] [12] of the EU project Ambient Networks [13] as well as in papers presented at international conferences [14] [15]. In this paper we will focus on the three last aspects and we also further extend the analysis and results presented in [1] [16] [17].

In this paper we introduce a distributed decision making algorithm that both enables and exploit the cooperation, i.e. the algorithms used for establishing the cooperation and for performing the access selection and handover. We then evaluate the impacts from both as network perspective, in terms of network utilization and service availability, as well from a user perspective. Hence, we can identify three research questions related to:

- Selection of decision making parameters for access selection
- What kind of technical benefits new decision making algorithms potentially result
- How improved network performance and service availability translate into user satisfaction

For the user aspects of the network cooperation we want to analyze the impact of different levels of service availability on the user experience.

The rest of this paper is organized as follows; in Section 2, we outline related work, introduce most relevant Ambient Networks (AN) concepts for distributed decision making and address what is missing. User experience and the User Satisfaction Index (USI) model are explained in Section 3. The decision making algorithm and the used handover model are illustrated in Section 4 and an example of evaluating the discovered radio accesses is given. The simulation model and settings used in our performance evaluation tests are described in Section 5. Section 6 presents the technical simulation experiment results and analyse them from network and operator viewpoint. Section 7 presents the user satisfaction analysis based on the presented technical results. In Section 8, we discuss on further challenges of a decision making in *Future Internet* like networking environments. Finally, in Section 9, we present the conclusions of our work.

2. Related work

2.1. Operator and network cooperation

The integrated European Union (EU) project AN proposes a framework for dynamic cooperation between networks and business entities called *Network Composition* [4] [18] including both business and technical aspects [12]. Network sharing, international and national roaming are all well known examples of a cooperation between operators. One of the innovations with the Ambient Networks is that the cooperation between operators can be established dynamically, e.g. roaming between different local or national networks is possible without pre-negotiated agreements.

The framework for *Network Composition* identifies different levels of cooperation between networks, spanning from more looser/weaker cooperation on towards that two composing networks even gets integrated into just one network. This is to give support for the many various ways the network owners would like to cooperate with each other, and which would depend not only on the specific situation but also for example what kind of networks that would be composed, the legal and business status, etc.

The level of cooperation is modelled out from in what way a certain network has the right to access and control a certain Resource in a network. Before composition, a network has generally full control over its own Resources. After composition, the network might have rights to another network to access and control a certain set of Resources out of its own network, as well as has been given the right to access and control Resources in the other network. If shared control over a certain Resource is agreed, there is a need to create a new virtual control plane in order to manage and operate this shared control.

2.2. Multi-radio resource management and access selection

The AN project also considers Multi-Radio Architecture (MRA) where cooperation between different types of RATs is considered [19]. One example is a design of strategies and algorithms for Radio Resource Management (RRM) for a joint control of heterogeneous radio access networks, e.g. WLAN, Global System for Mobile communications (GSM) and Universal Mobile Telecommunications System (UMTS).

A number of projects have focused on network cooperation and resource control in heterogeneous networks [20] [21] [22]. In the FP5 project Monasidre a service and network resource management platform was developed focusing on radio access networks. The FP6 projects Everest and Aroma have been focused on strategies for efficient radio resources management in heterogeneous networks for support of end-to-end QoS. For both these project "Common RRM" has been a key feature for the management of radio access technologies. The Aroma project also included techno-economic evaluation of micro-cell and WLAN usage within 3G networks.

In the AN project not only multi-radio access is considered, but also multi-operator aspects which are one main theme in this paper. The AN MRRM provided common means to manage and control different radio access resources over network boundaries when the network cooperation were supported [23]. In addition, this paper makes use of the techno-economic modeling developed and used in the AN project [12].

2.3. Analysis of user experience

The authors of this paper have proposed the use of a set of performance metrics as a tool to measure user satisfaction in network cooperation compared to single operator networks. For this modeling and analysis of the user experience we have used the approach proposed by Pohjola & Kilkki [24]. In their proposed methodology value creation of services is modeled together with how users behave and put value on the experience. The assumptions on user perception and rating of service quality are based on the findings by Twersky & Kahneman [25]. They describe the use of Expected Experience and Expected Value function to represent user happiness. If the expected value increases or decreases from the expected value in the user happiness function an increment results in less additional "positive" experience compared to a larger "negative" experience for a corresponding decrement. This leads to different shape of "utility curves", i.e. how the utility for a user depends on different parameters of a service. Examples of utility functions as a function of bit rate are presented by Sachs et al [26].

This kind of "behavioral economics" proposed by Twersky & Kahneman has also been used by Mitomo et al [27] for analysis of consumer preferences for flat rate. Lambrecht & Skiera [28] have investigated consumer behavior related to flat rate charging schemes for Internet services.

Edell & Varayia [29] [30] present trial results on how users value different qualities of service (rate) for fixed Internet (broadband) access. Compared to the work by Edell & Varayia we extend the analysis to present and future wireless broadband services

User satisfaction in terms of throughput for multimedia traffic is analyzed in [31]. Badia et al [32] model the user

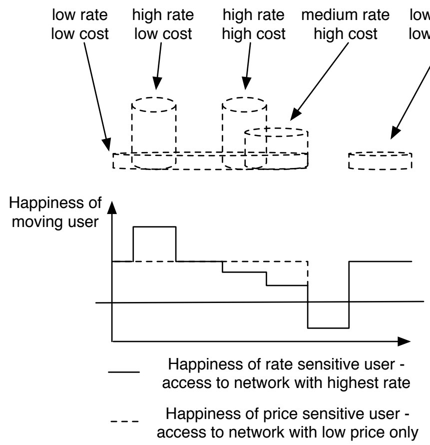

Figure 1. Sensitivity and happiness.

satisfaction taking into account requested Quality of Service (QoS), data rate and also price. This model enables analysis of impact of resource allocation on operator revenues.

Customer value related to value creation of services and products is the staring point of the "Value model" proposed by Lindstedt et al [33] [34]. The customer value is expressed as the ratio of *satisfaction of needs* and the *use of resources*. The resources can be time, money, efforts, etc.

Noriaki Kano proposed a customer satisfaction model (Kano Model) that challenged traditional approaches [35] [36]. Different service attributes are not seen as equal by the customers, "some attributes produce higher levels of satisfaction than others". Different consumers will value different attributes differently and hence different consumer categories can be identified.

3. User experience

In this section we will describe our approach for modeling and evaluation of the user experience. The results are based both on simulations, where we estimate the service availability for different levels of cooperation between networks, and on a user survey with focus on the perceived importance of different parameters.

First we will provide an overall description (an illustration) of our approach. Next, based on established modeling and methodology, we will discuss different ways to describe and model the user experience of services and the related customer satisfaction or dissatisfaction.

3.1. User perception and network cooperation

Cooperation between wireless operators is usually seen as means to reduce network costs. Network cooperation may result in a wide spectrum of advantages for both the users and the operators. Network sharing will result in lower costs for the cooperating partners. Such lower costs may or may not result in lower prices for the users. In this paper our main interest is the potential to improve the service coverage and quality.

For the users the cooperation between networks with different coverage will lead to an increased availability and perceived service quality and hence more satisfied users. This may lead to increased usage as well as willingness to pay for the services and hence potentially more revenues. More satisfied users will be more loyal to the operator and hence cost related to churn may be reduced [37].

As an illustration we will assume that the "User happiness" is related to two factors only; the price and the quality of the connectivity service. We consider a set of users and an analysis over a number of time units T_j. For each time unit of duration T_j we consider the perceived service quality Q_j and the price P_j. We assume that the users in every time unit are able to select a new type of network (assuming that the network cooperation allows that), each with its own quality and price. Equation (1) shows how "User happiness" is calculated for one user.

$$UserHappiness = \sum_j Q_j T_j / P_j \quad (1)$$

The "User happiness" increases with increasing service availability and quality and with decreasing price. A simple illustration on the use of this modeling approach is shown in Figure 1. Moving users can be connected to networks with different data rate and price characteristics. Wide cylinders indicate networks with wide area coverage and the heights indicate capacity (or average data rate). High data rate and low price imply a high "User happiness". Disconnection results in a low or even a negative "User happiness".

3.2. General aspects and modeling of user perception

In Section 3.3 we will introduce a more general performance metric called User Satisfaction Index. The USI takes into account both the service quality, availability and the price. In our simulation experiment, to be presented in Section 7, the end-user perception of the service (USI) is calculated based on the technical parameters, e.g. the number of connected mobile nodes.

One way to describe the user value or satisfaction is to consider the total utility for the user, the "price" paid and the corresponding production cost and profit for the service provider. From the consumer perspective there is a "surplus" if the perceived user utility exceeds the price. From the provider perspective the offered price is the production cost plus some profit. The profit is kept secret to the consumers and the consumers want to keep the consumer surplus secret to the producers. If the producer finds out that the consumer surplus is very high, then the price can be increased without any major complaints and hence, the profit is increased. In summary, the user (consumer) tries to maximize the consumer surplus and the producer tries to maximize the profit (i.e. price - cost). In addition, With the utility model described above the consumer surplus can be described as "added value" in different dimensions; e.g. access to a service or product, time saving, ease of use, convenience, etc. However, the "price" in this utility model usually is related to money only, but the "cost" for the consumer could be extended to include other aspects where the consumer need to "pay" in other ways, e.g. by allocating time, to provide own work or different sorts of "inconvenience".

This type of reasoning is one of the main characteristics of the "Value model" proposed by Lindstedt et al [33]. The $Customer\ Value$ is expressed as a ratio of "Satisfaction of needs" (SN) and the "Use of resources" (UR); Equation (2). The resources can be any combination or function of time (t), money (m) or effort (e), i.e. $f(t, m, e)$.

$$Customer\ Value = SN/UR \tag{2}$$

The function ($f(t, m, e)$) can most often not easily be described in general terms. Assume for example that the function is a product or a sum of the individual functions $f(t)$, $f(m)$ and $f(e)$. Assuming the product of separate functions, then a very small (or zero) value, e.g. price = 0, would lead to a very large (or infinite) customer value. Assuming a sum of individual functions combination would requires some form of "weighting", and this would probably be very case dependent.

Noriaki Kano has developed an approach based on "Attractive Quality Creation" that usually is referred to as the "Kano Model". This model has been used for development of new products and services and to determine market strategies.

When this approach was presented Kano challenged the traditional Customer Satisfaction Models based on an assumption that "More is better". This assumes that the better the provider can perform on each service attribute the more satisfied the customers will be. This would e.g. imply a more or less linear relationship with different attributes, e.g. if the bit rate of a communication service is increased 10 times then the satisfaction of the customer will increase 10 times.

In the proposed customer satisfaction model (Kano Model) it is assumed that the performance on product and service attributes is not equal in the eyes of the customers. Performance on certain categories attributes produces higher levels of satisfaction than others. In addition, different consumers can value different attributes differently

Figure 2. Kano Model.

An illustration is shown in Figure 2 where three types of different customer response to a service is shown [38]. The traditional assumption on customer behavior, i.e. "more is better" is denoted "Satisfier". Another type called "Delighter" is a customer that appreciates more attributes (and performance). Finally, a customer that requires that the service always includes all possible attributes and have the best possible performance, i.e. there are a lot of "must bes" , is called a "Dissatisfier".

In the Ofcom studies of consumer experience and decision making [39] [40] a number of factors was identified describing different aspects of user satisfaction. Some factors are called "emotional", e.g. the trustworthiness of the brand and how highly other people rate the brand of the operator. Most listed factors can be denoted "rational/tangible" and can be grouped into different categories:

- Network related factors: reliability of coverage, ease of use of network services, reliability and speed of the connection.
- Factors related to the price and service offers: low cost, amount of data that can downloaded, ability to get bundled offers and "value for money"
- Factors related to customer care: technical support and customer service

3.3. Our approach - USI model

In our modeling approach we have used two starting points i) users have some level of expectation about the service availability and quality and ii) the impact of "no service", i.e. disconnection needs to be taken into account. For the aspect of "expected experience" we have used the Twersky & Kahneman findings about changes in service levels. If the quality is decreased by some amount this has a much bigger negative impact than the corresponding positive im-

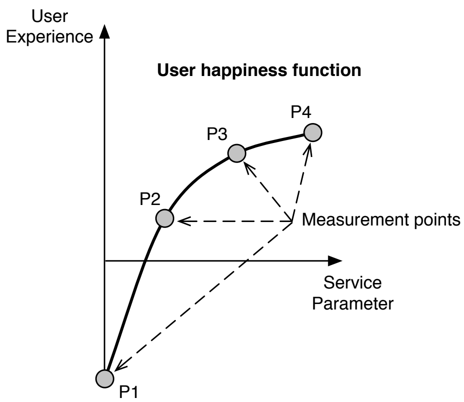

Figure 3. User happiness function.

Focus	α	β	χ	δ
Connection	-1	1	1	1
Connection/Quality	-1	0.25	1	1.4

Table 1. P value weight sets.

pact of an equally large positive change. When it comes to disconnection we model this with a negative value of the experience. A zero value for the user experience would imply that the user "does not care".

In our modeling we define a performance index called User Satisfaction Index. The USI model is based on the user happiness function of 4 levels. These levels represent different perceived service qualities using different P values; $P1$, $P2$, $P3$ and $P4$, see Figure 3.

The value $P3$ represents the user happiness when the service parameter has the expected value. $P2$ and $P4$ represent the user experience when the service parameter is lower or higher than the expected value. $P1$ corresponds to the case when there is no service, i.e. no connection. As Figure 3 illustrates, the better the expectations are satisfied, the happier the user will be.

Four levels were selected based on the assumption that a user always has a certain expectation level based on which the perceived service quality can be evaluated. This expectation level can vary based on various things like a service type, user's earlier experiences and so on. This assumption alone leads to 3 different levels and is sufficient as such to model the quality sensitivity. However, in order to model also the connectivity sensitivity, we need to differentiate disconnections, when there is no perceived service, from the situations where a user perceives the service quality that is worse than expected. So in order to model both the connectivity and the quality sensitivity, 4 different levels are required. The model could be extended by introducing more measurement points to model different perceived service qualities, but for the sake of simplicity, we settled down to 4 levels, which was a trade off between accuracy and simplicity. It should be noted that some (non-elastic) services might not tolerate large range of fluctuation in the service quality level resulting in an unusable service if only the perceived service quality corresponds $P2$.

Equation (3) presents the USI for user i, where K is a number of services, X ,Y, Z and W are numbers of P value measurements. α, β, χ and δ are P value weights and $Cost$ is the end user price per data unit. Equation (4) is used to calculate the overall USI of all users.

$$USI_i = \sum_{j=1}^{K}(\alpha \sum_{i=1}^{X} P1_{ij} + \beta \sum_{i=1}^{Y} P2_{ij}/Cost_j + \chi \sum_{i=1}^{Z} P3_{ij}/Cost_j + \delta \sum_{i=1}^{W} P4_{ij}/Cost_j) \quad (3)$$

$$USI_{all} = \sum_{i=1}^{L} USI_i \quad (4)$$

In the USI analysis, two different P value weight sets as represented in Table 1 are considered. The first set has its focus on connectivity and it does not differentiate between $P2$, $P3$ and $P4$ values and therefore the same weight value is used for the corresponding weights β, χ and δ. The second set extends the first one by differentiating the quality levels and as a result of this, different weight values are assigned for $P2$, $P3$ and $P4$ values.

The first P value weight set corresponds the services tolerating quite well short temporal connection breaks like a web surfing. Respectively, the second P value weight set is typical for the real time services.

3.4. User survey for the USI - data collection

In order to verify the modeling assumptions used for the estimation of the USI metric a user survey was conducted on user perception of services. The survey included three parts

- Part one consists of one open question "what are the most important aspects for usage of wireless broadband and selection of service offers?".
- The second part includes rating of different statements on how the person would perceive different levels of service quality, e.g. availability and delivered data rates.
- In the third part the persons were asked to rate "the attractiveness" of different service offers for wireless

broadband access with different prices, data rates and amounts of usage.

30 persons participated in this "small" survey. Two types of users were included in the survey; telecom people (students at technical university) and "ordinary users" (non-engineers). The participants were asked about their experience of wireless broadband access and where the access was used: at home, at the office/school or in public places. Most participants used some WLAN and/or 3G wireless access on a regular basis.

The objective of part one was to confirm that our "assumed" parameters were the ones that were considered important when the service quality or service offers were evaluated. People were asked to list parameters that were considered important and to provide a motivation. We counted how many persons did mention a specific aspect as having a high degree of importance.

The objective of part two was to get an indication on how people perceive service quality and how they "value" different aspects. People were asked to rate (from -10 to +10) how they did perceive service availability and the delivered data rate assuming a specific value of the expected data rate.

The objective of part three was to get some insight about reasoning when choosing between different offers, how trade-offs are made and what parameters that were considered most important.

4. Algorithm and handover model

In this section, interdependencies between cooperation and decision making are explained to elaborate the importance of network cooperation for a distributed decision making algorithm and to show how diverse environment the decision making should cope with. The decision making algorithm is described with a high level pseudo code and the formula for calculating the cell rank values based on the different constraints is presented. The handover model used in the simulations and its state machine is explained including different kinds of delay contributing to the overall handover execution time as perceived by an end-user.

4.1. Cooperation and decision making

Cooperation can be characterized with 2 different types of agreements: Horizontal and vertical agreements. Horizontal agreements represent a cooperation between network providers. For example, when service continuity is preferred for an existing connection, it requires a horizontal agreement between old and new network providers. Naturally, overlapping operator coverage areas provide a

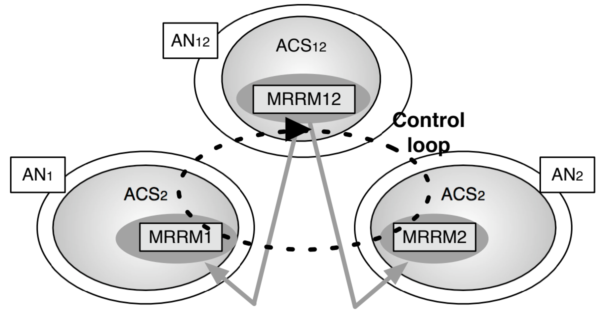

Figure 4. Control Sharing of the MRRM control functionalities.

good base for the cooperation between operators to support (seamless) inter-operator HandOvers (HOs) and load balancing.

Vertical agreements are used between network and service providers. This type of agreement represent a cooperation based on which for instance information is collected from a service provider to be taken into account in a distributed decision making process.

Let us consider an example of *Network Composition* when being applied to MRRM, the trade-offs in regard of the performance of access selection, and which should be considered when composing two ANs.

In Figure 4 we let the two networks $AN1$ and $AN2$ compose in order to share the control of their MRRMs, resulting in that a new virtual $ACS12$ is created with a virtualized $MRRM12$ executing within this Ambient Control Space (ACS). For its implementation, it is likely that each of the two composing ANs will instantiate a virtualized MRRM, which will communicate with each other to provide the shared control of the underlying MRRMs. Thus, through $MRRM12$, the control of access selection is distributed and shared, with the capability to select any of the available access networks (subject to their respective status as described above). It should then be observed that due to the distributed aspect of decision making, the time of the control loop for access selection will be extended, and will not be able to respond as quick as if control was made locally (but then of course without the possibility to roam seamlessly between the two ANs). The implementation of a distributed algorithm depends on the used composition type. For instance, in case of delegated MRRM control, a decision making and access selection is more like "centralized" solution where we should expect the time for the control loop that should be close to the time for the local control loops in the non-composed ANs.

A distributed decision making framework should be able to operate on top of diverse business landscape where technical agreements between networks and players like Ser-

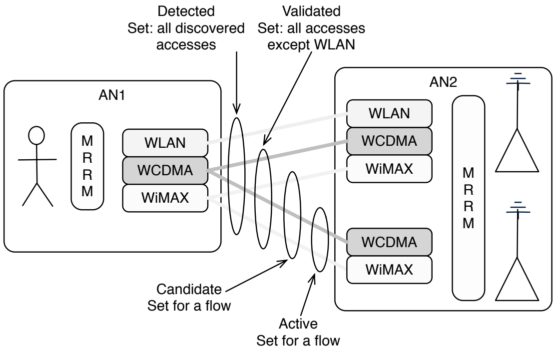

Figure 5. MRRM access sets.

vice Level Agreements (SLAs) realize the business relationships. Algorithm distribution means that relevant information is gathered and used according to existing horizontal/vertical agreements in the decision making.

4.2. Decision making algorithm

Figure 5 shows the MRRM sets based on which the access selection is done in the AN architecture. There are four sets:

- *Detected Set* contains all detected access resources by a terminal
- *Validated Set* contains all access resources from the *Detected Set* that are validated by policy functions and are usable
- *Candidate Set* contains all access resources from the *Validated Set* satisfying the given requirements like the resource requirements of a flow
- *Active Set* contains the selected access resources for a flow

The algorithm is using these sets with a few exceptions. First, we do not use *Validated Set* since our simulation model does not include any special access policies. Secondly, our algorithm uses extended access sets, i.e., there are two different *Candidate Sets* representing both terminal and network preferences. The algorithm execution starts in a terminal based on a trigger generated either in the terminal or network. A terminal is naturally the only entity able to detect what cells are in its coverage. After this, the detected cells are communicated to the network side and where each cell is ranked based on the network's preferences. A terminal does the same for each cell. Finally, both the terminal and network cell ranks are considered together to decide what cell is the best one.

Algorithm 1 shows a high level pseudo code of the access evaluation and selection algorithm, which is executed once in a time unit. The algorithm gets a set of mobile nodes

Strategy Name	α	β
Terminal	3	1
Network	1	3
Legacy	1	1

Table 2. Algorithm weights.

as input parameter. After this, the order in which the mobile nodes are processed is randomized. For each mobile node, first the $DetectedSet$ is constructed. This set contains all radio cells a mobile node can detect and which have enough available resources according to the mobile node's demands. Once the $DetectedSet$ is done, then each cell in it is evaluated according to Equation (5) and the resulting cell rank value is added to the $CellRanks$ vector. If the cell with the highest rank is not the one, which the mobile node is currently using, then a handover is performed and the $ActiveSet$ is updated with the new cell info.

```
Input: Set of mobile nodes
Output: Error status
randomize the order of mobile nodes;
foreach Mobile node i do
    Read current mobile node status;
    Update mobile nodes location info;
    Construct DetectedSet;
    foreach Cell j in the DetectedSet do
        Calculate cell rank value;
        Add the rank value to the CellRanks;
    end
    BestCell = CellWithMaxRank(CellRanks);
    if CurrentCell != BestCell then
        Perform handover;
        Update the ActiveSet;
    end
end
```

Algorithm 1: **Update MN states.**

In Equation (5), CR_i is the cell rank value for cell i, α is the *Terminal Centric* algorithm weight and respectively β is the weight for the *Network Centric* algorithm. The algorithm assumes that there is N numbers of constraints for terminal (tc) and M numbers of constraints for network (nc).

$$CR_i = \alpha \sum_{j=1}^{N} \lambda_j tc_j + \beta \sum_{j=1}^{M} \kappa_j nc_j \qquad (5)$$

The algorithm weights α and β are adjusted based on the used algorithm strategy. For the *Network Centric* algorithm $\alpha > \beta$ and correspondingly for the *Terminal Centric* one

$\beta > \alpha$. For the legacy, the same weight value was used for both algorithm weights. Table 2 shows the used weights for each strategy.

4.3. Constraints

In the simulation model, all constraints are classified according to two distinct factors; i) based on the value type of a constraint (binary constraint vs. non-binary constraint) and ii) based on how constraint's conditions should be satisfied (hard constraint vs. soft constraint). Table 3 lists the used constraints, their types based on this classification and their constraint weights. Three first constraints are handled in the terminal and the rest are handled in the network side.

As illustrated in Table 3, the constraint specific weights are only defined for the soft constraints. The hard constraints that are used for qualifying evaluated cells according to the constraint's conditions, the weight value 1 is used in the cell rank calculation. The sum of all terminal/network soft constraints is equal to 1.

Signal strength constraint prefers a stronger radio signal. This is perhaps one of the most significant constraints used in legacy systems to perform access selection.

Selection of RAT constraint prefers the discovered cells that are in the current RAT and it is used to minimize inter-RAT HOs. Respectively *Selection of operator* constraint prefers the discovered cells from the current operator.

Cell load levels and *Service load levels* constraints are used for load balancing. The former is used to prioritize the cells with lower load over the highly loaded ones assuming that cells' load levels exceed the load balancing threshold. The latter does the same for service types.

Roaming agreement and *Supported service type* are both binary hard constraints and they are used to disqualify the cells that belongs to the operator either not having a valid Roaming Agreement (RA) or not supporting the requested service type.

4.4. Calculating cell ranks

Let's consider a simple example without using the real values to illustrates how the $CellRank$ vectors are constructed and used. Let us assume that there are 2 cells (a, b) in the $DetectedSet$ and that there are 2 terminal constraints (A, B) and network constraints (C, D). First, both terminal $(tc_A = \lfloor tc_{a,A}, tc_{b,A} \rfloor, tc_B = \lfloor tc_{a,B}, tc_{b,B} \rfloor)$ and network $(nc_C = \lfloor nc_{a,C}, nc_{b,C} \rfloor, nc_D = \lfloor nc_{a,D}, nc_{b,D} \rfloor)$ constraint vectors are constructed. After this, the constraint vectors are normalized, i.e. a vector element value is between 0 and 1, and multiplied by the constraint specific weights and summed together resulting $CandidateSets$ for terminal (Equation (6)) and network (Equation (7)).

Constraint name	Constraint type	Weight
Signal strength	non-binary/soft	0.6
Selection of RAT	binary/soft	0.3
Selection of operator	binary/soft	0.1
Cell load levels	non-binary/soft	0.6
Roaming agreement	binary/hard	1
Supported service type	binary/hard	1
Service load levels	non-binary/soft	0.4

Table 3. Constraint types.

$$T\_CS = [\sum_{i=1}^{2} \lambda_i tc_{i,a}, \sum_{i=1}^{2} \lambda_i tc_{i,b}] \tag{6}$$

$$N\_CS = [\sum_{i=1}^{2} \kappa_i nc_{i,a}, \sum_{i=1}^{2} \kappa_i nc_{i,b}] \tag{7}$$

Next, both $CandidateSets$ are multiplied by the terminal algorithm (α) and the network algorithm (β) weights and summed together resulting the $CellRanks$ vector consisting of two elements, one for cell a (Equation (8)) and another one for cell b (Equation (9)).

$$CR_a = \sum_{j=1}^{2} \alpha \lambda_j tc_{j,a} + \sum_{j=1}^{2} \beta \kappa_j nc_{j,a} \tag{8}$$

$$CR_b = \sum_{j=1}^{2} \alpha \lambda_j tc_{j,b} + \sum_{j=1}^{2} \beta \kappa_j nc_{j,b} \tag{9}$$

The $ActiveSet$ is then constructed based on these cell rank values as illustrated in Equation (10), i.e., the cell with a higher rank value is forming the $ActiveSet$.

$$AS = \max(\sum_{j} CR_j) = CR_k, k \in [a, b] \tag{10}$$

4.5. Handover model

The HO model combines the radio and application connectivity states. The model consists of five states; *disconnected*, *connected*, *session association*, *radio bootstrapping* and *handover execution*. All applications are using the same session association delay of one time unit. For UMTS, it was assumed that this radio technology is attached all the time due to its low power consumption compared to

Transition	Conditions
A	Simulation start-up.
B	Out of coverage. No available access resources.
C	New radio access discovered.
D	New radio access ready.
E	HO finished successfully and a session needs to be (re)associated due to the HO type or due to the application type change during the HO.
F	The discovered new radio bootstrapped successfully.
G	HO finished successfully and no need to re-associate a session.
H	Session (re)associated successfully.
I	HO initiated with a radio bootstrapping.
J	HO failed and the old cell not available.

Table 4. State transition conditions.

WLAN, which is kept de-attached, if not in use. The bootstrapping time of WLAN was set to one time unit.

For HO execution delays, the UMTS and WLAN performance results from [11] were used as base and a "basic" HO type within a single RAT was chosen to last one time unit. Other types (inter-RAT and inter-operator HO) were chosen to last twice as long as the delay of intra-RAT HOs, i.e. two time units.

In the beginning of a simulation, the bootstrapping delays are not used, thus all Mobile Nodes (MNs) are able to move directly into the *connected* state assuming that enough radio access resources and the requested service type were available. So from an end-user perspective, the overall effective HO execution time is the sum of a HO delay, a radio bootstrapping time and a session association time. Table 4 explains under which conditions the state transitions occur in the handover model represented in Figure 6.

Inter-RAT HOs are not supported by the legacy algorithm, which is always forced to perform a radio re-association when switching between RATs resulting a short period of disconnection. The *Network Centric* and *Terminal Centric* algorithms are supporting Inter-RAT HOs inside an operator network and between operators' networks with the cooperation.

5. Simulation model

In the simulation setup, two operators and two service providers were used. Both operators had a SLA with their service provider and they provided the same RATs, one access network with 45 WLAN cells and another with 2 UMTS cells. WLAN cells had the radius of 80m and UMTS

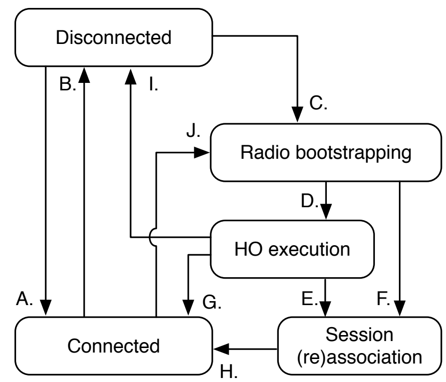

Figure 6. State machine.

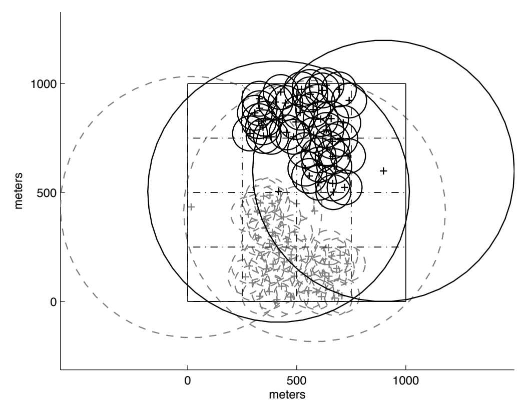

Figure 7. Radio cell topolocy.

cells had the radius of 600m. The simulation area was one square kilometer. Radio cell deployment in the simulation area is presented in Figure 7 where one operator cells are presented with grey dashed lines and another ones' with black solid lines. The number of mobile nodes for the scalability tests varied between 100 and 800 MNs, and for other kinds of technical and the USI measurements 300 MNs were used.

For the scalability and the USI tests, the *Network Centric* and legacy algorithms were compared. The *Terminal Centric* algorithm was omitted from these tests, since as clearly showed by other technical evaluations, it finished second after the *Network Centric* algorithm.

The MNs did not follow any particular movement pattern, thus they were moving according to random movement model based on the following limitations;

- Starting locations are randomized based on the uniform distribution,
- The maximum speed of a MN is 10 m/s,

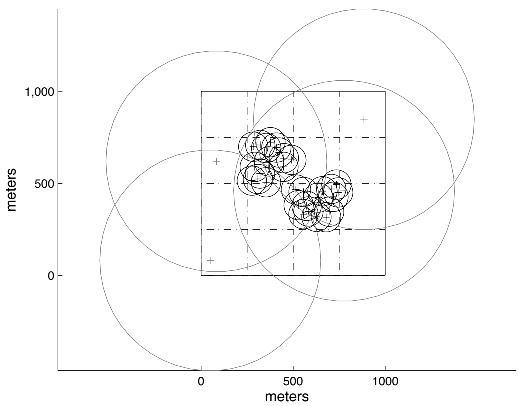

Figure 8. Operator-1's cell topology.

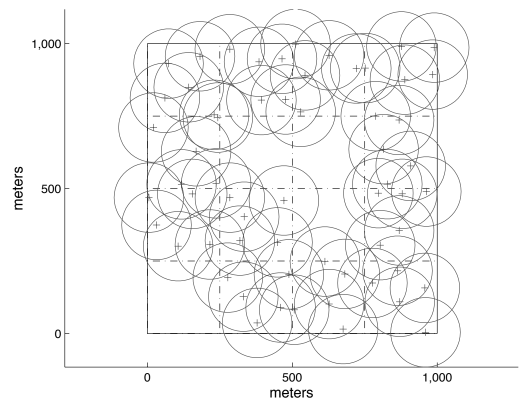

Figure 9. Operator-2's cell topology.

- There are no idle moments for any MN, and
- A random $\pm 90°$ movement direction change probability is used.

The MNs had an application running all the time and there were two supported service types. Each MN had an application usage vector defining what application type is used and when. These vectors were randomly generated for each MN based on the uniform distribution. If a MN requested the service type that was not available at the MN's current location, then the MN went to the $disconnected$ state and did not reserve any access resources.

Other working assumptions were as follows;

- Each MN supports WLAN and UMTS accesses,
- Each MN supports a HO between and within a RAT and operator when the network side implements such HO,
- Cell loads are measured in terms of an abstract measure for traffic load called *traffic units*,
- Each cell has circle shape coverage area and signal strength S is defined as Equation (11), where d is the distance between a MN and the cell origin and R is the cell radius, and
- Cooperation between operators also includes RA.

$$S = \max[0, 1 - (d/R)] \qquad (11)$$

5.1. Competitive Multi-operator Simulation

In parallel with the USI simulations, an additional set of access selection algorithm simulations was run in the business environment consisting two competing operators having overlapping radio access network coverage. The business environment consisted of the operator-1, who was multi-access provider with full coverage of wide-area UMTS over the simulation area and a few dense WLAN hotspots (see Figure 8) and the operator-2, who was a legacy operator providing almost full coverage of short/mid range radio coverage (see Figure 9). The operator-1 multi-access network supported inter-RAT HOs according to the handover model described in Section 4.5. Because of the competition between the operators, in these simulations, HOs between the operator networks weren't possible. However, both operators had roaming agreements to provide access for any mobile node. In other words, all mobile nodes in the simulation could be considered as roamers and mobile nodes could change operator networks via bootstrap (which is more costly than handover).

In the essence, the simulation setup for the competitive multi-operator simulations was pretty much identical to the one presented for the USI simulations in Section 5. However there were some obvious differences, such as the in the business environment and in the radio coverage due to different configuration.

6. Evaluation - network and operator aspects

In this section, we illustrate the technical simulation results in Section 6.1 to show how a distributed decision making algorithm performs against the legacy algorithm and what kind of technical benefits the network cooperation results in. Additional simulation results are presented in Section 6.2 to show how the evaluated algorithms perform in a different kind of networking environment.

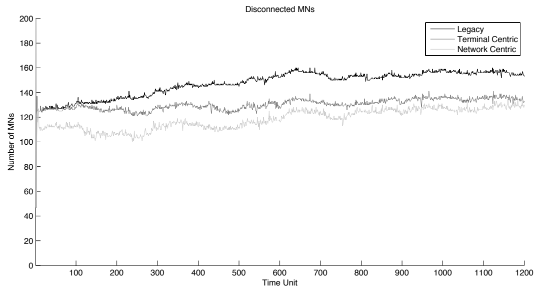

Figure 10. Disconnected MNs - No cooperation.

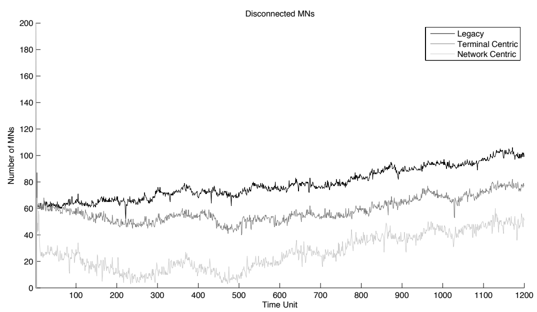

Figure 11. Disconnected MNs - Cooperation.

6.1. Network cooperation analysis

One of the main goals of these simulations is to study what kind of (technical) benefits the new distributed access selection algorithm defined in Section 4 could potentially result with and without the network cooperation. Figure 10 illustrates the disconnectivity measurements for each evaluated algorithm without the cooperation. As can be clearly seen, both the *Network Centric* and the *Terminal Centric* algorithm perform better than the legacy one. An interesting finding is how the *Terminal Centric* performs; in the beginning it is close to the legacy but then it starts to gain gap to the legacy and to approach the performance of the *Network Centric* algorithm. A high number of disconnected MNs is the result of two factors. Firstly, without the network cooperation, a MN is limited to the use of one operator, which allows it to use only a single type of service. Secondly, there occurs temporary congestion in the simulation area, because the available network resources are not uniformly distributed as explained in Section 5, i.e., WLAN hotspots populate only approximately 38% of the simulation area.

The corresponding measurements with the cooperation between operators are showed in Figure 11. All three algorithms perform better than without the cooperation, which was expected. The *Network Centric* and the *Terminal Centric* algorithms can better exploit the network cooperation as showed in the figure. And this is the reason why for instance a gap between the *Network Centric* and the legacy is bigger than it was without the network cooperation.

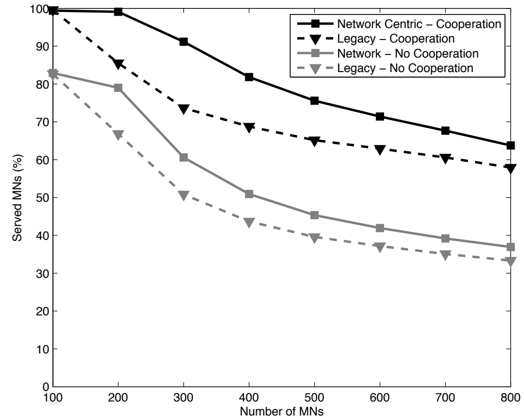

Figure 12. Served MNs.

The scalability measurements for the *Network Centric* and the legacy algorithms are shown in Figure 12. For low network load like with 100 MNs, it does not matter whether the cooperation is used or not. When the network load is increasing, the difference between the cases is becoming clearer. It can be noted that the difference between algorithms is bigger with cooperation than without it. The *Network Centric* algorithm is able to better maintain its capability to serve users with a heavy network load.

After the network load increases over 300 MNs, the differences between the cases with and without the cooperation are getting smaller, but the *Network Centric* algorithm still yields approximately 30% improvement in the network utilization compared to the legacy. Network utilization increases slightly less when the cooperation is not present due to the lack of extended access coverage and supported services. These results indicate that the cooperation results in better effective network capacity and more served users. For an average user, the cooperation means more stable connection and less connection breaks because handovers are supported by the horizontal agreement (cooperation) between the operators.

But all these technical benefits do not become without a *price*; i.e., an increased number of HOs as shown in Table 5. The *Network Centric* algorithm results in the highest number of any kinds of HOs, i.e. over two times more intra-RAT HOs than the legacy case. In practise, this results in more effective load balancing, which can be seen as increased utilization of the available network resources. The *Terminal Centric* algorithm is once again finishing second.

		Intra-RAT	Inter-RAT	Inter-oper.
No Coop				
	Legacy	1.63	0	0
	Terminal	2.77	0.29	0
	Network	3.76	0.36	0
Coop				
	Legacy	4.45	0	0
	Terminal	6.60	0.51	0.41
	Network	9.90	0.56	0.77

Table 5. HO statistics (avg. HOs per MN).

6.2. Competitive multi-operator analysis

Main goal of the competitive multi-operator evaluation was to study how the *Network Centric* and the *Terminal Centric* access selection algorithms perform against the legacy algorithm in the case of multi-access operator and single-radio (legacy) operator.

Key interest and main evaluation metric was set to the network resource utilization in the operator networks, when the requested network load from the MNs was close to and exceeding the combined operator network capacity. In the simulation case, it was also assumed that the service provider has unlimited resources, thus the access network resources were the only limiting factor. Additional results are available in [41] [42].

One additional goal and reason for these simulations was to verify the earlier results [43] [44] that did indicate clear performance gain for the the *Network Centric* and *Terminal Centric* algorithms. While the differences between the algorithms decreased from the earlier results, due to the more detailed modelling of radio access handover and bootstrapping, the trends remained the same.

Figure 13 shows the network resource utilization for the measured three algorithms with 400 MNs and the requested network load of 600 Traffic Units (TUs). The figure also includes fourth graph, which represents the theoretical maximum of the network resource utilization calculated by a linear programming Linear Programming (LP) technique, called Mixed Integer Programming (MIP) [45]. The MIP finds one of the optimal solutions, if it exists, and reports unfeasibility otherwise; therefore it is commonly used in network planning to obtain (theoretical) upper bounds on performance.

The graphs in Figure 13 illustrate the key finding of the simulation results; In the multi-access network, the *Network Centric* and *Terminal Centric* algorithm graphs are clearly closer to the theoretical maximum graph than the graph of legacy algorithm. This indicates that network resource utilization is better for the new algorithms. In addition, the

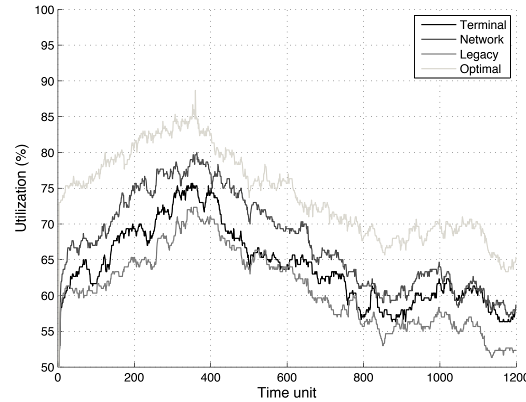

Figure 13. Operator-1's network utilization.

simulation result confirmed expected trend for the single-radio network; studied sophisticated access selection algorithms cannot improve network resource utilization in such environment.

Moreover, Figure 13 shows that in the multi-access network the highest network utilization is gained, when the *Network Centric* algorithm is used. The benefit is quite steady through out the simulation period and can be as high as 10% compared to the legacy algorithm. Further on, the figure shows how the *Terminal Centric* algorithm graph behaves less steadily, but still outperforming the legacy algorithm most of the time.

7. Evaluation - user and usage aspects

The evaluation of user experience is based on two main types of results. First, the results from the user survey on "important aspects" and on the impact of different parameters are presented. Next, the technical results on network utilization and service availability presented in presented in Section 6.1 are interpreted using the User Satisfaction Index model introduced in Section 3.

7.1. Results of user survey

The objective of part one was to confirm that our "assumed" parameters were the ones that were considered important when the service quality or service offers were evaluated. People were asked to list parameters that were considered important and to provide a motivation. We counted how many persons did mention a specific aspect as having a high degree of importance. The following aspects were mentioned:

- Availability & coverage
- Data rate (speed) important

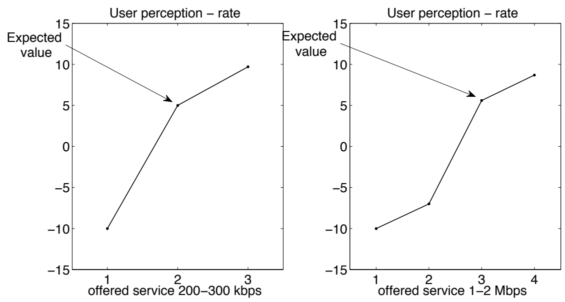

Figure 14. User perception & delivered data.

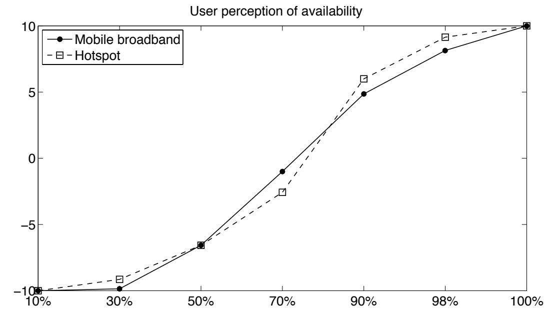

Figure 15. User perception & availability.

- Data rate not so important if availability is OK
- Security and reliability
- Price level
- Type of subscription
- User terminal & interface
- Ease of use

The results to a large extent confirmed our own assumptions of selection of "most important" parameters. Parameters considered to have "high importance" were "availability & coverage" (mentioned by 85%) and "price" (mentioned by 80%). "Security & reliability", "ease of use" and "type of subscription" was mentioned by 50-60% of the participants.

Half of the persons mentioned "data rate" as being important, but it is interesting to note that equally many answered that data rate "is not so important" provided that the service availability is satisfactory.

The results of the second part on perception of service quality confirmed the findings by Twersky & Kahneman [25] when it comes to the user experience as being related to an expected value and also the "shape" of the "user happiness" function in Figure 3. Less than expected data rate resulted in a quick drop of perceived experience whereas an increase resulted in a much lower increase of the perceived experience. This is illustrated in Figure 14.

As an example consider the case where a user has a General Packet Radio Service (GPRS)/3G/HSDPA card in the laptop. If the user expects an ordinary UMTS connection then a 200 kbps data rate may correspond to the expected service. If HSDPA is available providing a 2 Mbps data rate the user probably not will be 10 times happier, but still happier. If HSDPA is available but the delivered data rate is 200 kbps the user experience will be much lower, all depending on the expectation of the user. In the same way if only a GPRS connection is available with e.g. 20 kbps data rate the user will get even more disappointed.

Also for the service availability the perceived experience decreased quite rapidly with a lower availability, see Figure 15 for average values. It is interesting to note that for individuals the transition from "good" to "very bad" was more rapid than indicated by the average values shown in the figure. When the availability went under some (personal) threshold then the rating in most cases rapidly went down to the lowest level (-10). This result is well in line with the results in the Ofcom results discussed previously indicating very high user value for coverage and availability.

When it comes to the third part of the survey, to rate "the attractiveness" of different service offers, no clear pattern could be observed in decision making and the trade-off analysis. It may be that the sample size was too small. It turned out that the group "students" frequently used WLAN (for free) but not 3G (where payment was needed). People in the other group either had 3G subscriptions (often through their employer) or did not use wireless broadband at all. However, price seems to be the single most important parameter. The offers with lowest price got ratings between +5 and +10 and the offers with highest prices got ratings between -10 and 0.

7.2. Estimation of User Satisfaction Index

The average per user USI measurements with 300 MNs using the first P value weight set ($[-1, 1, 1, 1]$) are presented in Table 6 including the number of connected MNs and the normalized and absolute USI values. The USI value normalization is done so that the user without any period of disconnection has the normalized USI value 100 corresponding the absolute USI value of 1200 ($= 1200 * P4\ weight$). In the same way, a user disconnected all the time would have the value -100 corresponding the absolute USI value of -1200 ($= 1200 * P1\ weight$).

These measurements support the technical results showed in Section 6. Less time being in disconnected mode as showed in Figure 12 and increased service availability as presented in Figure 11 naturally affect and increase the user happiness as it can be seen from the USI values.

In practice, the first P value weight set $[-1, 1, 1, 1]$ represents the user behavior where the user is always equally

	Connected MNs	USI	Norm. USI
Legacy - No Coop	51%	21	2
Terminal - No Coop	57%	158	13
Network - No Coop	61%	255	22
Legacy - Coop	73%	569	47
Terminal - Coop	81%	733	61
Network - Coop	91%	988	82

Table 6. Connection and USI statistics with the first weight set.

	Connected MNs	USI	Norm. USI
Legacy - No Coop	51%	-126	-8
Terminal - No Coop	57%	37	2
Network - No Coop	61%	150	9
Legacy - Coop	73%	740	45
Terminal - Coop	81%	949	57
Network - Coop	91%	1227	74

Table 7. Connection and USI statistics with the second weight set.

happy whenever connected, i.e., different quality levels are not modeled. The negative value of $P1$ results in a high impact of disconnection.

Table 7 shows the USI measurements for the second P value weight set ($[-1, 0.25, 1, 1.4]$). The USI value normalization is done in the same way as for the first weight set with the exception that now the value range of the absolute USI value is [-1200,1650]. The second P value weight set results in different USI values since now different quality levels are distinguished, i.e., it does matter "how a user is connected". The negative weight value of $P1$ (disconnection) and a relatively low $P2$ weight value result in a negative USI value for the legacy case when the cooperation is not supported. When the cooperation is included, the situation gets better as indicated by a higher USI value; -126 vs. 740.

Both distributed algorithms perform better than the legacy one, but their performance is also relatively poor without the cooperation. This was expected, since without the cooperation both the access and service resources are limited. The *Network Centric* algorithm outperforms the *Terminal Centric* one but the difference is smaller than in the case of the first P value weight set, because in this case the P value distribution does matter.

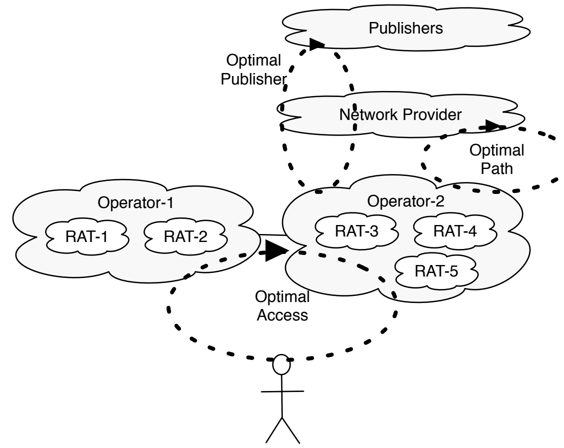

Figure 16. Multi-operator network scenario.

8. Extensions

The *Network Centric* and *Terminal Centric* algorithms were also considering end-users' communication needs like the requested service type, as the service availability were possible to consider through configuration of policies and profiles in the MRRMs, see Figure 4. This is especially an important aspect when we cannot assume that all services are equally reachable through all provided accesses. In addition to this feature, we discuss in this section future challenges of a decision making system while moving towards an *information centric* networking. Thus the *information centric* networking shifts the focus from looking at network as connected host towards a network connecting information producers with consumers. Related *information centric* work is research by Van Jacobsen [46] and yet another vision for a *information centric* networking is provided in [47].

One key feature is the introduction of caches in the network, data can be also stored at network nodes not only hosts. This leads to the situation where the same information can be available at multiple locations. The decision making system should with the *information centric* networking extended the access and services focus to also include content and delivery aspects, see Figure 16. In practise, this could mean for instance that the availability and location of temporary content storages ("caches") are also taken into account while evaluating and selecting available accesses. It is evident that the overall decision making system needs a common objective and the overall objective in the *information centric* networking is the performance of the application interaction Inter Process Communication (IPC) between different devices. This objective can utilize the set of different decision making subsystems (publisher, path and attachment subsystems) and the overall decision algorithm can apply them in different procedural combinations. How the actual algorithm and subsystems should be combined is for further studies.

The selection of service and data source includes the capability to determinate where the suitable candidates reside, i.e. the location of the service/data. The selection process should in normal case only require a network resolution function (source location selection). The resolution phase is clearly challenging as the future network integrates multiple caches in the network and the location selection is believed to have many identical data and service located in many places in the network. Here the 'closest' location typically is the best selection, however the 'closest' match can be challenging to understand as user and provider objectives and algorithm structure can vary.

It has to be clear that subsystem selection (subsystem optimization) can be contradictory compared to the overall performance. However the general method used in the described decision making is to include subsystem through weights for parameters and subsystems as contention can be addressed in a deterministic and fair way. On an algorithm level is the subsystem design clearly easier said than implemented, however the goal is to design a self-adaptable decision making system, which could be implemented for instance using both algorithm and constraint weights and adjust those when needed in order to change the decision making system's emphasis.

SLAs used between operators and service providers represent a fairly static nature of the network configuration whereas content caches are dynamic. This inherently implies that the decision making system has different timing phases and reaction times. The proper timing consideration should be addressed in the overall decision making. The timing properties can be handled such that faster decision loops contain more static parameters, e.g. faster decision loop includes more static selection criteria. The service and data delivery is handled through the path subsystem, however the path characteristics can change during data and service delivery. This is similar to the fast changing characteristics of the attachment subsystem like when the physical radio condition changes. The timing order of selection criteria updates for the overall decision making system is:

- Attachment criteria (fastest updates)
- Path criteria (faster updates)
- Publish criteria (fast and slow updates)

The future work will focus on the subsystem design of the optimal publisher and optimal path algorithms and how they should be interacting with the access selection process described in this paper. Some observations, the access selection is naturally limited to the geographical area of the user and the somewhat limited number of accesses available. On the other hand, the design of path and publisher criteria and algorithms are not limited to a geographical area and to design a scalable solution can be hard to achieve. The delivery based on the path subsystem is well known for the potentially NP complete problem alas it is impossible to find an optimal solution. These challenges will be further addressed in the 4WARD project [48].

9. Conclusions

We have shown that network cooperation, e.g. based on the *Network Composition* framework, has an essential role when designing a distributed decision making algorithm. Such algorithm is beneficial for the overall user experience when users are able to roam between access networks belonging to different providers. The way two provider networks like to compose is indeed a matter of business relations and trust between operators. Nevertheless the way composition is being performed also has an impact on the performance of the access selection. This should generally be taken into account when determining the wanted user experience. As the HO statistics presented in Section 6 indicates, the performance of a distributed decision making algorithm is also based on means to support HOs between RATs and operators indicating the importance of having powerful and flexible tools to support the network cooperation.

The general indication is that the additional coverage and supported services achieved through the network cooperation will increase the amount of potential customers that can be connected. Also, the attached customers would be more satisfied when their connections are more stable. This is the result of being able to freely select access network according to a richer set of constraints including both end-user and network preferences.

In general, the two new decision making algorithms worked as expected and resulted in network performance improvements. When the network traffic is close to or exceeding the congestion border, the algorithms are able to better exploit the available network resources than the legacy algorithm. Two simulation experiments resulted in different kinds of technical benefits due to their different simulation settings. The results in network cooperation simulations (multi-access environment) showed that the *Network Centric* and the *Terminal Centric* algorithms outperformed the legacy one in all measured technical metrics. Because these new algorithms were better able to exploit the network cooperation, the gap between them and the legacy algorithm was even bigger when the network cooperation was present. The results in competitive multi-operator simulations indicate that the power of the *Network Centric* and the *Terminal Centric* is in their capability of balancing the load between the available RATs in case of congestion, whereas in a single-radio case such option is not possible. It is also noticeable how well these two new algorithms were able to perform under a heavy network load compared to the legacy algorithm. When the mobile nodes' requested network capacity was in the range of 65%-110% of the maximum capacity, these new algorithm were still able to maintain approximately 30% higher number of connected users. This shows clearly how well these algorithms scale compared to the legacy one.

We have proposed and illustrated the use of a methodology to model and analyze the user experience of connectivity services. A main part in the analysis is the proposed performance metric called User Satisfaction Index (USI) which provides a mapping of the value of service parameters (e.g. data rate, availability) onto user experience. With different types of weights used in the mapping different types of services and different types of user perception can be modeled.

We have conducted a user survey on connectivity service parameters and user perception of services. The results support our choice of decision making parameters and are also in line with the parameter selection in Ofcom analysis on customer experience. The survey also provides useful input for selecting what kind of weight sets are used in the USI model and measurements.

The service availability and quality is related to the "short-term" (e.g. for each application session) user experience. Customer support and pricing have an impact on the long customer satisfaction. The former factor is not included in our study, but the latter is and the USI model covers it on a short-term basis. The current development with monthly flat rate subscriptions implies that the USI modeling and analysis will be of interest mainly for user experience of service availability, reliability and quality.

The technical simulation and USI results support each other. In a multi-access environment, the network cooperation results in gains for all evaluated algorithms indicating also better scalability. Clear benefits can be identified both for providers and for users, the overall traffic increases and the number of disconnected users decreases. As the USI results in Section 7 shows the type of application and the used algorithm affect on how the gained technical benefits translates into additional user satisfaction. When the used application is not quality sensitive, higher normalized USI values were achieved.

During recent years, the payments from international roaming have been one of the best source of profit for the mobile operators. However the situation is changing, when "wild west" style roaming pricing is no longer unheeded by the European Commission and upper bound for the roaming payments have been set in Europe. This decision will cut roaming profit considerably and is likely to drive operator towards new business cases and models. The problem in the essence in the new situation is how to cut operational costs from the operator-to-operator traffic. One solution has been growing in size, expand the coverage geographically and that way avoid the situation in general. But growing in size has its limits.

Alternatively, network and service operators in Internet have been fighting similar problems already years, while trying to minimize their transit costs. Internet's way of solving the issue has been establishing direct peering and sibling links between operator networks where applicable and where both sides of the agreement have seen the benefit. One of the most successful "peerer" worldwide is Google, who has enabled very vast low transit cost network through peering agreements with non-Tier-1 operators. In the middle of Fixed Mobile Convergence, maybe this suggests that national and local roaming (e.g. peering between operators) is something to be taken under serious consideration also in the mobile networking world and the concepts represented in this article are supporting this business evolution option.

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