Towards realization of the ABC vision: a comparative survey of access network selection

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***Abstract*— Access Network Selection (ANS) providing the most appropriate networking technology for accessing and using services in a heterogeneous wireless environment constitutes the heart of the overall handover management procedure. The aim of this paper is to survey representative vertical handover schemes proposed in related research literature with emphasis laid on the design of the ANS mechanism. Schemes' distinct features are analyzed and the authors discuss on their relative merits and weaknesses.**

Keywords- always best connectivity; vertical handover; access network selection

I. INTRODUCTION

Future communication systems will be increasingly complex, involving thousands of heterogeneous nodes with diverse capabilities and several networking technologies with different characteristics and capabilities. Specifically, next generation wireless networks are migrating to 4G systems, involving heterogeneous access networks, such as mobile communications systems (2G, 2.5G, 3G, 3.5G), Long Term Evolution (LTE), Wireless Local/Metropolitan Access networks (WLANs/WMANs), Wireless Personal Area Networks (WPANs), ad-hoc networks, sensor networks, short range communications as well as Digital Video/Audio Broadcasting (DVB/DAB). Diverse networking elements will interwork with the aim to provide users with ubiquitous access to information and advanced services at a high quality level in a cost efficient manner any time, any place in line with the always best connectivity (ABC) principle [1].

ABC concept provides users with the ability to connect each time with the most appropriate network in order to access the requested service(s) according to current network conditions, user preferences, requirements and constraints service profiles, terminal capabilities and contextual information. At the same time, users should remain unaware of the heterogeneity of the underlying infrastructure as well as of its potential modifications, ensuring service continuity and consistency in the overall service area.

The realization of the ABC vision falls within the realm of handover management procedures, which should be flexible and efficient, while involving multi-criteria complex considerations and trade-offs.

Handover management involves 1a) deciding on the appropriate time to initiate a handover (so as to minimize communication overhead and avoid unnecessary handovers), 1b) selecting the most suitable access network for a specific service (the respective problem is referred to as Access Network Selection – ANS) and 1c) maintaining service continuity, while it is generally decomposed in three phases: 2a) information gathering, which involves detecting all available networks and collecting all relevant information for identifying the need/opportunity to perform handover, 2b) handover decision, which comprises the decision making process for selecting the most appropriate access network, exploiting information gathered during the first phase and 2c) handover execution, which involves transition to the new network point of attachment in accordance with the selection made during the previous phase, as depicted in Fig 1 [5]. The heart of the overall handover procedure (and of the ABC vision) is the second phase providing a solution to the ANS problem.

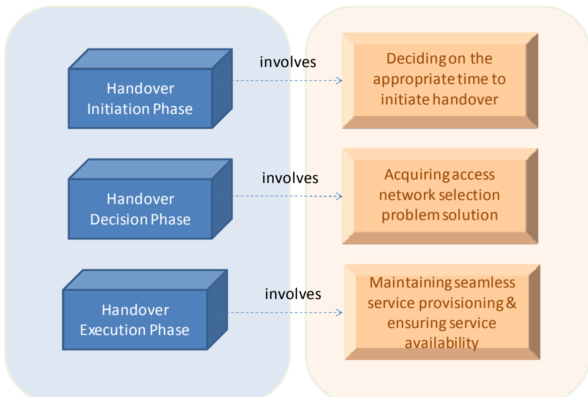

Figure 1. Handover phases.

Traditional handover decision strategies followed in a homogeneous environment (e.g., horizontal handover should take place in case Received Signal Strength – RSS – falls below a certain threshold value) are not sufficient in the context of heterogeneous systems. Additional criteria should be considered and evaluated, such as user requirements, preferences and constraints (as given in the user profile), service and application characteristics & capabilities, terminal capabilities, contextual information (user velocity, user location, terminal battery status), network conditions (link quality, coverage, bandwidth supported, delay, load conditions), cost imposed and security related aspects. Taking into account the multiplicity, the volatile and dynamic nature of the aforementioned aspects, as well as potentially unexpected situations, handover is constituted an extremely complex decision process. Even though handover procedures have received considerable attention by the researchers as a key challenge in the context of 4G systems [2-15], the proposed ANS schemes lack unity, while a number of issues still need to be resolved.

The aim of this paper is, as a first step, to survey representative handover schemes proposed in related research literature with emphasis laid on access network selection decision process. Their distinct features are analyzed and the authors discuss on their relative merits and weaknesses. As a next step, the authors identify critical aspects that should be considered in the design of ANS mechanism, making a step towards ABC realization.

The rest of the paper is structured as follows. Section 2 discusses on handover classification dimensions. Section 3 presents a number of different ANS schemes proposed in the related research literature. Section 4 discusses on various aspects indentified, while section 5 concludes the paper and highlights our future plans.

II. HANDOVER CLASSIFICATION DIMENSIONS

Handover may be classified in accordance with the following aspects. First, handover may occur a) within the same cell (intracell handover) utilizing a different to the currently employed radio channel), b) between different cells of the same network (horizontal handover) and c) between different types of networks (vertical handover). Second, the handover may be categorized as a) Network Controlled/Mobile Assisted (NCHO/MAHO) when a network related entity is responsible for controlling and conducting the handover, exploiting information and measurements gathered form the mobile terminal and b) Mobile Controlled/Network Assisted (MCHO/NAHO) when the mobile terminal has the primary control over the handover exploiting information provided by the network. The main advantage of NCHO/MAHO system lies in the fact that the overall network load can be better balanced, due to exploiting more accurate knowledge of the network's conditions as the decision point is located in the network. On the other hand, in MCHO/NAHO approach, the decision depends on local conditions and metrics measured by the mobile terminal. This facilitates and improves the performance of the handover initiation decision. Third, handover may be characterized as imperative or alternative. Imperative handover is triggered by physical events (e.g., when the RSS falls below a predefined threshold) and should be performed fast in order to maintain existing connections. Alternative handovers are performed so as to provide users with better performance. Fourth, a handover is characterized as upwards when it occurs between a network supporting high data rate but small coverage and a network achieving higher coverage but lower data rate. The opposite stands for downwards handovers (i.e., the mobile node moves from a large network cell with a low data rate to a small network cell which supports high data rates. Fifth, the handover is soft/smooth when the mobile terminals create a connection to the target point of attachment prior to the release of the previous attachment point. The mobile terminal may listen to a set of candidate access points at the same time before selecting one of them. It is also referred to as make-before-break handover and is a pre-requisite for achieving seamless mobility. In the opposite case, when the new connection is established after the release of the old one, the handover is characterized as hard or break-before-make handover. In such a case, the mobile terminal is able to communicate each time with only one access point.

Another aspect to be considered is the design of the components that are involved in the overall handover process. Components should be a) aware of the existence and adaptable to various wireless networking technologies, b) capable of handling more complex and dynamic situations, c) able to manage user's mobility, maintaining seamless service provisioning and d) have low power requirements. To this respect, handover requires multimode user terminals, either using multiple radio interfaces or a single reconfigurable radio interface adapting to different wireless networks exploiting the Software Defined Radio (SDR), while they should be provided with a friendly graphical user interface to specify & alter user preferences, requirements and constraints in an easy manner.

III. RELATED RESEARCH OVERVIEW

Vertical handover management is an active area of research [2]. In [3], [4] and [5], the authors categorize vertical handover decision algorithms based on the decision criteria used and/or the methodology employed to obtain a solution. In [5], the authors classify vertical handover decision strategies into five main categories: function-based, user-centric, multiple-attribute decision, fuzzy logic and neural networks based and context-aware strategies. Following handover strategies comparative evaluation, they propose a Mobile Controlled vertical Handover (MCHO) decision approach considering a context-aware based scheme using policies with a Fuzzy Logic System performing the handover initiation stage, while network selection involve: a) criteria scoring (the importance of each decision criteria is evaluated according to user preferences), b) network scoring (the available networks are evaluated and compared for each handover decision criteria) and c) Analytic Hierarchy Process (AHP) method as a Multi Objective Decision Model (MODM). Finally, handover execution establishes the IP connectivity through the chosen IP connectivity using Mobile IP functionalities to ensure service continuity.

In [6] a decision process for a network-assisted network selection is provided that combines non-compensatory and compensatory multi-attribute decision making algorithms (MADM) jointly performed on the network side to assist the terminal to select the top candidate network(s). Specifically, after retrieving relevant information from the network entities for use in the decision making, the list of candidate networks is narrowed by using disjunctive and conjunctive non-compensatory MADM algorithm, while the narrowed list is further refined using TOPSIS, a compensatory MADM algorithm. The compensatory MADM algorithm ranks alternatives in order of preference. The network calculates the rankings of the available access networks and provides them to the terminal, constituting the approach resource efficient from the wireless bandwidth utilization perspective. Their proposed solution performs the non-compensatory MADM part of network selection for each individual service requested, uses a compensatory MADM algorithm for each individual service requested, while the final network selected will be based on the average of rankings for the networks of each service. The architectural framework considered involves a Data Collection Node (DCN) for collecting network characteristics, Service Announcement Node (SAN) for providing services related data and Authentication, Authorization and Accounting Node (AAA) for AAA information. These entities provide input data to a network-based assessment entity that calculates network rankings for use by the terminal in network selection. In addition, the terminal provides its location and any other information that could be considered by the network in the analysis.

In [12] the authors develop a process to evaluate three packet switched networks (UMTS, WLAN and GPRS) in reference to the QoS offered and select the network that offers the highest standard for QoS. Specifically, after identifying the most important QoS indicators that characterize packet-switched networks, two methodologies are proposed combining the Analytical Hierarchy Process (AHP) and Grey Relational Analysis (GRA) methods. Both proposed methodologies calculate the relative weights of each QoS parameters, which will be used to fill the AHP matrices.

In [13], an architecture capable of supporting ABC services is proposed. The designed access discovery mechanism supporting collection of QoS related information of the available Radio Access Networks (RAN) integrates Service Location Protocol (SLP) and Location Service (LCS). The access network selection offers personalized choices to users by formulating a multi-criteria decision making problem as single objective multi-constraint optimization problem, enabling users to change weight factors and constraints according to their requirements and preferences. Finally, seamless handover mechanism is based on Mobile IPv6 which supports end-to-end QoS.

In [7], the authors analyze the implications of the “ABC” vision in integrated UMTS/ WLAN network context. They identify major requirements, reveal important issues that arise, point out the limitations of current UMTS/WLAN standards from an “ABC” viewpoint. In the sequel, they propose a generic always best connected utility-based model, aiming to maximize user’s utility by allocating finite resource to meet the QoS requirements of applications along multiple QoS dimensions, considering also the cost imposed to the user by this allocation. The general ABC problem is formulated as a Generalized Assignment Problem (generalized form of the knapsack problem), which is NP-hard. However, even in case a large problem size occurs, approximation algorithms may be employed to reduce the required computation time. Finally, they present an object-oriented design of real-time UML model for an ABC mobile system.

In [14], the authors propose an intelligent utility-based network selection strategy for a multi-access network scenario. They focus on non-real time services, while the utility-based algorithm accounts for user time constraints, estimates service completion time by considering available information on the networks’ recent history (averaging the previous five rates experienced in a particular network) for each available access network and then selects the most promising access network based on consumer surplus difference (i.e., the difference between monetary value of the service to the user and the actual price charged).

In [8], the issue of provisioning one-to-many services over heterogeneous wireless networks in terms of how to choose the access network (AN) that satisfies the bandwidth requirements of services, while maximizing the system profit in the combined network is addressed. Specifically, a heterogeneous network comprised of Multicast Broadcast Multimedia Service (MBMS) of the third generation mobile terrestrial network and the Digital Video Broadcasting System for Handheld terminals (DVB-H) is considered. An algorithmic framework for the network selection for one-to-many services (NS-OMS) is described. It comprises three main parts: A. Constraints and Goals, which identify the constraints to obey and the objectives to achieve when solving the NS-OMS problem, each adjustable according to specific requirements of different network operators and service providers, B. Service Scheduling, which determines in what time and which requests are ready for resource allocation to determine the most appropriate AN for those requests and C. Resource Allocation for the selected services and AN. Both networks cooperate and complement each other to improve resource usage and to support one-to-many services with their multicast and broadcast transmission capabilities.

In [9] the authors develop a QoS negotiation-based vertical handoff scheme to balance against user satisfaction and network efficiency. Specifically, they consider user preferences, network conditions and application requirements in terms of QoS parameters (including RSS, bandwidth, delay, BER and cost) incorporating them in a merit function in order to find the best possible network for users. Prior to the merit function application, a time-adaptive network discovery method is considered, adapting the interface activating interval so that the power consumption on interface activation is decreased. Additionally, the merit function is integrated with a time-adaptive QoS measuring system in order to ascertain that the performance of the selected network is consistently the best. The QoS factors are normalized and combined in the merit function by adopting a logarithm-based normalization method. The weights of the parameters can be calculated by AHP or assigned directly by the user when a call is initiated and then tuned dynamically according to the perceived QoS. The network with the largest merit function value is preferred and put at the top of the candidate list. In order to account for the network operators interests, the final decision is made after negotiating with the network operators, as the network operators may accept handoff requests selectively in order to maximize resource utilization and long-term revenue without violating some QoS constraints, This network-centric decision problem is formulated as a semi-Markov decision process and solved by means of Q-learning, while only network capacity is considered as a QoS constraint. In case of a QoS violation, the call request (new call or handoff call) is rejected. Otherwise, an action is chosen according to the optimal policy. Specifically, if acceptance has the higher Q-value, the call will be accepted; otherwise, the call will be rejected. Finally, the predicted result is sent to the user informing him/her whether the handoff request is accepted. The authors present numerical results to demonstrate that the proposed scheme outperforms existing user centric schemes in terms of long-term network revenue.

In [11] a market-place agent-based architecture is proposed, where users can detect wireless network services, negotiate with the identified providers about price and service features, select the best service and finally configure their devices in accordance with the selected service. System architecture comprises three layers: the network layer, mobility support – network connectivity layer and a third layer that mainly supports users in acquiring the most appropriate service. The third layer incorporates three types of agents: the user agent, the marketplace agent and the ISP agent. A negotiation between the agents may be triggered either by the user of the ISP. The role of the marketplace agent is to facilitate the communication between sellers (ISP agents) and buyers (user agents).

In [15], the authors propose a user-centric network selection scheme in conjunction with power-saving interface management and adaptive handover initiation solutions at the terminal side to support seamless mobility and power utilization efficiency. Network selection performs in two phases: pre-selection and utility-based decision making. In the pre-selection phase, undesirable access networks will be eliminated from the candidate list (e.g., access technologies whose corresponding radio interface is turned off according to the interface management policies, access networks belonging to the black list established in the experience repository, access networks that do not support the services required by the user). After the pre-selection, the proposed solution evaluates the utility for each remaining candidate access network, taking into account the user preferences configuration. Network selection criteria comprise information that the terminal can measure or estimate without information provisioned by the network; cost, power consumption gain, maximum achievable data rate, access network load and link quality. A multiplicative aggregate utility approach to evaluate the candidate access networks is considered, while the selected access network is the one that leads to the highest quality. Power consumption in a terminal device with multiple wireless interfaces is optimized by keeping one interface active at a time for communication, while high-power consumption rate interfaces (e.g., WiFi, WiMAX) will be turned off in case the remaining battery lifetime is less than a predefined threshold in order to prolong the device's lifetime. Additionally, user's location plays an important role to the consideration and significance of the power saving criteria. Finally, an approach is presented for adaptively computing the received signal threshold indicating triggering of network selection and handover execution.

In [10] the authors incorporate autonomic computing concepts in PROTON, a proposed policy-based system for assisting users in the access network selection process. PROTON's architecture is divided into network- and terminal-side components. Network-side components contain the components related to the specification and deployment of policies. Terminal-side components are organized into a three-layered system (Context Management layer, Policy Management layer and Enforcement layer). The proposed policy model builds on the concept of Finite State Transducers, while policies are evaluated using information from context to manage mobiles' behaviour.

IV. Discussion

As a first note, the proposed schemes lack unity, while a comprehensive list of critical aspects and their implications to the design of an ANS mechanism is missing from related research literature. Their objectives may differ along with the entity that undertakes the responsibility and control of the whole procedure. Specifically, network centric schemes address the ANS problem from the network operators' perspective, aiming mainly at efficiently managing network resources and fulfilling current users' requests, while maximizing their revenue. On the other hand, user-centric schemes, which address the ANS problem from the users' side, aim at assisting and enabling users to find and associate with the most appropriate access network for service provisioning, focusing on satisfying user requirements, preferences and constraints, without however considering efficient network operation. User-centric approaches generally fall within two distinct categories: a) Mobile Controlled Network Assisted (MCNA), according to which a user - related entity residing in the mobile terminal's domain undertakes the task of acquiring ANS problem solution, exploiting information provided by the network and b) Network Controlled Mobile Assisted (NCMA), where a network – related entity considers information & measurements gathered from the terminal in order to decide on the "best" access network for service provisioning. Network-centric schemes follow mainly NC approach. Most schemes in related research literature adopt the MCNA user-centric approach (e.g., [5], [6], [12], [13], [14], [15]) being more flexible and relieving the network from the overall complexity, while they are considered to be an imperative property of the 4G environments to ensure ABC.

Considering the fact that if a network is heavily loaded it cannot accommodate new user requests (at least without degrading the quality of currently connected users) and user requests could be rejected by network operators in order to maximize long - term revenues or reserve resources for their "premium" users, the user and network – centric problems could co-exist within the same framework and potentially interwork through a negotiation phase [9], [11]. However, this is not commonly found in related research literature.

A critical factor for designing an ANS mechanism is the decision parameters to be taken into account and evaluated for obtaining a solution. In [5], decision criteria are grouped in four categories: network related (i.e., coverage, bandwidth, latency, link quality, monetary cost, security level), terminal related (e.g., velocity, battery power, location information etc.), user related (i.e., user profile and preferences) and service related (service capabilities, QoS, etc.). Some of the criteria are considered static as changes do not incur often (e.g., user profiles, terminal characteristics), while others are highly dynamic (e.g., network conditions).

In general, the ANS potential solutions should satisfy user preferences, requirements and constraints (both QoS related and budget related), take into account service/application characteristics in conjunction with network characteristics and capabilities, consider terminal capabilities & contextual information concerning the environment of operation, cost imposed for utilizing network resources, power consumption and security related aspects. ANS schemes proposed in related research literature have identified various network characteristics as potential criteria, while subsets of them have been used in their decision making strategies. They may be grouped as following: a) link quality, evaluated considering indicators such as RSS, Carrier to Interference Ratio (CIR), Signal to Interference Ration (SIR), Signal to Noise and Interference Ration (SNIR), b) network availability, considering coverage, bandwidth availability & call blocking probability, c) QoS related aspects, considering throughput, delay, latency, jitter Bit Error Rate (BER), packet loss ratio, average number of retransmissions per packet and d) network reliability, considering call dropping probability and handover execution failure probability. Contextual information may comprise current network load conditions, terminal velocity, terminal location, and remaining battery lifetime in order to support power utilization efficiency in the overall selection process.

The decision methodology to be followed in order to determine the most appropriate access network for service provisioning is another significant factor in the context of ANS. ANS is a multi-criteria (MCDM) decision problem, thus, it could be solved adopting multi-objective (MODM) and/or multi-attribute (MADM) related methodologies and algorithms (e.g., Multi Attribute Utility Theory, Technique for Order Preference by Similarity to Ideal Solution, Analytic Hierarchy Process, Simple Additive Weighting, etc.), which is the most common case in related works ([5], [6], [7], [8], [9], [11], [12], [13], [14], [15]). MCDM algorithms can be used in combination with fuzzy logic when input attribute values are not clearly defined in order to develop advanced decision methodology handling imprecise or incomplete information [5]. Additionally, MCDM based methodologies could be adopted exploiting additionally contextual information. Finally, various systems have been proposed in related research literature following policy-based strategies. Policy-based systems are claimed to be sufficient for handling complexities in 4G systems, avoiding complex decision models and cost – functions due to their computing constraints and lack of flexibility [10].

In related research literature, power utilization efficiency has been addressed mostly in the context of information gathering phase [9], [15], while it may form a decision criterion considered in the ANS decision process [15].

As a final note, only a few related efforts introduce and exploit learning from experience schemes to the overall ANS process. The authors believe that incorporation of advanced learning capabilities to the entities involved in the ANS process could significantly enhance and improve the quality of the decision reached. Table I summarizes the basic characteristics of the presented related efforts with respect to the aforementioned categorization.

V. CONCLUSION

In this paper, a representative set of Access Network Selection schemes proposed in related research literature are surveyed, while their distinct features and relative merits and weaknesses are discussed. The authors conclude that the proposed schemes lack unity, while a comprehensive list of critical aspects and their implications to the design of an ANS mechanism is missing from related research literature. In this perspective, the authors believe that that incorporation of advanced learning and autonomous negotiation capabilities to the entities involved in the ANS process could significantly enhance and improve the quality of the decision reached. We plan to continue our work towards that direction, which could hopefully form the basis for defining a unified framework in the future.

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TABLE I. BASIC CHARACTERISTICS OF PROPOSED ANS SCHEMES IN RELATED RESEARCH LITERATURE

Ref. No.	Objectives/ Control	Decision Criteria	Methodology	Context	Power Efficiency	Negotiation	Learning
[5]	User-centric MCHO	User preferences Network characteristics	MCDM/ Fuzzy with Policies	Yes	No	No	No
[6]	User-centric MCHO/NAHO	Network characteristics Terminal capabilities User preferences	MCDM	Yes	No	No	No
[7]	Network centric (maximize users utility) MCHO	User preferences Network characteristics Application requirements	MCDM	No	No	No	No
[8]	Network – centric NCHO	Network characteristics Application requirements	MCDM	Yes	No	No	No
[9]	User – centric & network centric MCHO	User preferences Network characteristics Application requirements Terminal capabilities	MCDM & Q-Learning	No	Yes	Yes (Limited)	Yes (operator's side)
[10]	Network – centric MCHO	Network characteristics Terminal capabilities	Policy	Yes	No	No	No
[11]	User-centric & network centric MCHO	User preferences Network characteristics Terminal capabilities	MCDM	Yes	No	Yes (Fully)	No
[12]	User-centric MCHO	Network characteristics Application requirements	MCDM	No	No	No	No
[13]	User- centric MCHO	User preferences Network characteristics Application requirements	MCDM	Yes	Yes	No	No
[14]	User-centric MCHO	User preferences Network characteristics	MCDM	No	No	No	No
[15]	User – centric – MCHO	User preferences Network characteristics Terminal capabilities	MCDM	Yes	Yes	No	No