A Context-Aware Vertical Handover Framework Towards Energy-Efficiency

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Abstract – **Current mobile devices are equipped with multi-standard interfaces to fully utilize both the existing and the imminent Public Land Mobile Network infrastructure. This flexibility comes with significant energy consumption overheads at the mobile terminal side and thus, the adopted interface / network selection scheme, a.k.a. Vertical Handover mechanism, should be based on both Quality of Service oriented and energy-efficiency criteria. This paper summarizes the current state of the art on energy-centric vertical handover algorithms, discusses weak aspects of existing approaches and presents a novel context-aware vertical handover framework towards energy-efficiency. Rather than a pure energy-centric vertical handover scheme, this framework is a context-awareness enabler for energy-centric vertical handover decision making.**

***Keywords* - Energy efficiency, Vertical Handover, context-awareness, Quality of Service, heterogeneous networks, real-time monitoring, network discovery.**

I. Introduction

The exponential growth of emerging mobile services has resulted in an ever-increasing demand for bandwidth at the mobile terminal side. On the other hand, different purposes and different standard Radio Access Networks (RANs) have been extensively employed during the past few decades in a worldwide scale. Current mobile devices enable multi-standard support to fully utilize both the existing and the imminent Public Land Mobile Network (PLMN) infrastructure. Although multi-standard mobile terminals (MMTs) may resourcefully support multifarious QoS characteristics and provide seamless connectivity, significant energy consumption overheads are simultaneously introduced at the MMT side [1]. Since the MMTs are natively equipped with rechargeable batteries, energy consumption develops into a significant performance bottleneck for both the network and the MMT side. As a consequence, more sophisticated energy saving techniques are required to efficiently utilize the heterogeneous network infrastructure in a robust manner.

The network selection decision, a.k.a. Vertical Handover (VHO) decision, can play a key role for carrying out QoS-oriented yet energy efficient communications. The VHO procedure consists of three phases [2]: initiation, decision and execution. Each VHO policy is characterized by a set of VHO initiation triggers regarding either the network or the mobile terminal state, e.g. when the current network load exceeds a prescribed threshold or when the current Signal to Noise and Interference Ratio (SINR) at the mobile terminal falls below a predefined threshold. During the VHO decision phase the decision engine, i.e. the VHO decision entity, evaluates and accesses alternatives regarding the most suitable Point of Attachment (PoA) for the tagged mobile terminal. The VHO decision may be controlled either by the network or the mobile terminal side, although it can be facilitated by incorporating state information from both sides. Finally, the VHO execution phase is responsible for establishing the link between the mobile terminal and the target PoA, as well as to re-route the mobile terminal data-flow through the newly selected PoA.

In the context of energy-efficient heterogeneous network utilization, various parameters influence the robustness and the efficacy of the VHO procedure. Apart from parameters such as the SINR level or the network congestion, the VHO decision engine should also take into account parameters such as offered QoS on the target PoA, remaining battery lifetime at the MMT side, MMT energy consumption on the current PoA, MMT capabilities, charging policy, user preferences and so on. The plethora of parameters involved in the energy-centric VHO decision making combined with the heterogeneity of the underlying RAN environment, necessitates migration towards context-awareness. The innovative Cognitive Radio (CR) technology [3] is a perfect candidate to facilitate this migration and realize this novel communication paradigm. The CR terminals are envisioned to autonomously monitor their ambient environment, adapt their operating parameters in response to the incoming radio frequency (RF) stimuli, be aware of their internal state transitions and most importantly, build knowledge on previous history and past observations.

The remainder of this paper is organized as follows. Section II summarizes and discusses weak aspects of current state of the Art in the context of energy-oriented VHO decision making. Section III presents a novel context-aware VHO decision framework, capable of maintaining the required QoS level while simultaneously minimizing the energy-consumption at the MMT side. Finally, section IV concludes this paper and provides material for future work.

II. Related Work

A. Energy-centric VHO schemes

In the current literature, only a few approaches incorporate energy-efficiency as a VHO decision criterion [4-6]. The authors in [4] consider a tight coupling approach for an integrated Universal Mobile Telecommunications System (UMTS) / Wireless Local Area Network (WLAN) network, i.e. a single operator manages both the UMTS and the WLAN networks. A centralized decision entity, the Virtual Domain Controller (VDC), monitors and controls the VHO procedure on the network side. The MMT initiates a VHO request to the VDC in case a) the input or output queue exceeds over or falls below a predefined threshold or b) there exists a more energy efficient interface under the current traffic pattern. On the other hand, the VDC may reject a VHO request or initiate a VHO procedure if an overall network performance degradation is foreseen. The proposed scheme assumes that the uplink (UL) and downlink (DL) interfaces can be managed separately, e.g. transmit via the WLAN and receive via the UMTS interface. However, unidirectional interface utilization requires advanced signaling procedures, while the aggregated idle-time on both the DL and UL interfaces may result in higher overall energy consumption.

A tight coupling approach is also presented in [5], where the WLAN Access Points (APs) are emulated as cells in the UMTS core network and the MMTs are assumed to be capable of tracing their position either via GPS or cellular positioning methods. The MMTs are enabled to access location-oriented WLAN information through cellular paging channels and directly associate with a local WLAN AP, to ultimately avoid the energy-consuming WLAN network discovery procedure. Regarding the proposed VHO decision scheme, the MMT traffic is always served through the cellular network to preserve the offered QoS, except for long-lived bursty sessions where the WLAN interface is switched on and a VHO procedure from the cellular to the WLAN network is initiated.

A MMT-controlled VHO approach for an integrated UMTS/WLAN environment is proposed in [6]. According to it, the MMT autonomously selects the most energy-efficient interface for the current communication state (transmit, receive or idle) while it simultaneously switches-off the idle interface. The proposed state-by-state interface selection scheme assumes negligible interface switch on/off delay and energy overheads, while it additionally assumes that the connection with both the WLAN and UMTS network is not affected by the switching on/off procedure, i.e. the VHO signaling, delay, throughput and energy overhead are neglected.

B. *Discussion on existing energy-centric VHO schemes*

Current literature on energy consumption measurements and interface states [7-11] includes a plethora of divergent energy consumption measurements for different interface types and communication modes / interface states. This results from the fact that the energy consumption at the MMT side is highly correlated to a plethora of statically and dynamically changing parameters such as supported standard [7, 8], distance between the MMT and the target PoA [9], interface manufacturer [10], underlying computer engine [11], adopted interface state set [4-6], current channel state [9], and current traffic pattern characteristics [5]. As a consequence, the incorporation of fixed energy consumption values per interface state [4-6] may severely degrade the overall VHO scheme performance in practice.

On the other hand, the overall energy consumption is highly correlated to the sojourn times per interface state. Different interface state sojourn times characterize each service, determining thus different energy-profiles per service. However, existing energy-centric VHO approaches either neglect the energy-profile of each service [4], or assume a common energy-profile for all services (active state) [5].

The interface switching on/off policy and the required signaling for handing-over introduce non-negligible delay and energy overheads during the VHO execution phase. Thus, the VHO decision engine should weigh whether the resulting energy gain for utilizing a less energy-consuming PoA counterbalances the energy overhead introduced during the VHO execution. Existing VHO approaches [4, 6] do not account for these additional overheads during the VHO decision phase.

In addition, the energy savings derived by handing-over to a least energy-consuming PoA should not be at the expense of intolerable QoS deterioration at the MMT side. To accommodate this, the VHO execution delay, throughput and energy overheads should be incorporated in both the energy consumption and the QoS deterioration evaluation basis. The latter may drastically reduce the ping-pong effect, i.e. consecutive VHOs resulting from the MMT movement across the boundaries of the underlying RANs. The proposed VHO schemes in [4,6] do not account for these issues while [5] tries to avoid potential QoS deterioration by following a rather conservative approach where the MMT is always served trough the cellular network, except on long-lived and bursty traffic patterns where the MMT is serviced by the WLAN interface instead.

Existing VHO schemes achieve energy savings either a) by minimizing the required scanning/sensing time for WLAN network discovery [5] or b) by selecting the most energy-efficient PoA according to the current traffic type [4-6], e.g. bursty [5]. In the context of QoS-oriented yet energy-efficient heterogeneous network utilization, the former can be extended to include an energy-centric network discovery policy for acquiring the list of all accessible RANs, while the latter can be extended to include the least energy-consuming interface – PoA pair selection without compromising the offered QoS level. Both these operations require an energy-consumption and QoS evaluation basis built on context-awareness.

III. PROPOSED FRAMEWORK

This section describes an integrated framework capable of facilitating energy-centric VHO decision making by collecting and deriving context information. This framework consists of three auxiliary and one primary module residing in the MMT side. The first auxiliary module, referred to as Real-Time Monitoring Module (RTMM), is responsible for monitoring and gathering real-time raw-data on a wide set of energy-related parameters. The derived energy-related raw-data are subsequently exploited to build auxiliary VHO contexts at the second auxiliary module, the Context Fusion Module (CFM). The third auxiliary module, referred to as Network Discovery Module (NDM), is responsible for maintaining an up-to-date list of accessible PoA either by autonomous monitoring or by incorporating network side information. Finally, the VHO Decision Engine (VDE), the primary module, encompasses the auxiliary VHO contexts and the up-to-date list of all accessible

PoA to initiate, decide and proceed to a VHO procedure according to QoS-oriented and energy-efficiency criteria.

The proposed VHO framework is illustrated in Fig. 1. It should be noticed that the proposed framework is a context-awareness catalyst for energy-centric VHO decision making rather than an energy-centric VHO scheme. The remainder of this paper describes the individual functionality as well as the interactions between the VHO framework entities.

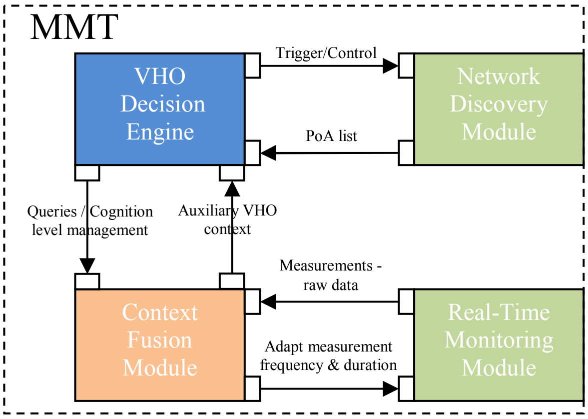

Figure 1: Proposed VHO framework

A. *Real-Time Monitoring Module*

The RTMM enables the derivation of auxiliary VHO contexts by providing appropriate raw-data measurements. These measurements may be based on MMT and/or network side information regarding the current MMT or PoA status. The MMT status may include current service, interface, battery and location status, while the PoA status may include channel, load and location status when the PoA is mobile, e.g. on MMT cooperation. An illustrative example of raw-data context information is provided in Table I.

Table I

MMT status						
Service	QoS class	Service type	Jitter	Delay tolerance	Rate	QoE
Interface	ID	Type / RAT	State	Tx power level	Transmission profile	
Battery	Current consumption	Energy consumption	Power consumption	Remaining lifetime		
Location	Coordinates	Direction	Speed			
PoA status						
General	PoA ID	PoA type	Channel State (SINR, RF level)	Instanteneous Rate	Capacity	Load
Location	Coordinates	Direction	Speed			

The MMT status raw-data can be either calculated or directly derived by accessing information residing in different protocol stack layers. For example, the RTMM may acquire the current channel state and the adopted transmission profile by encompassing physical (PHY) layer information. On the other hand, parameters such as the current interface state (transmit, receive, etc.) and the current PoA identity, can be acquired by encompassing Medium Access Control (MAC) layer information. The RTMM enables MMT self-awareness based on present cross-layer information, establishing thus the cognitive radio concept in the context of energy-efficiency. In fact, RTMM is actually a cross-layer optimized mechanism for acquiring energy-related raw-data.

The RTMM can be built on novel or existing mobile phone software development kits (SDKs) such as the Nokia Energy Profiler [12]. The latter is a preliminary RTMM enabling autonomous MMT energy consumption monitoring in terms of power consumption, current draw from the battery, cumulative energy consumption and so on. To further improve the efficacy and the adjustability of the real-time monitoring procedure, the frequency and the duration of the RTMM measurements should be dynamically adjustable in accordance with the required level of context-awareness.

B. *Context Fusion Module*

The CFM builds auxiliary VHO contexts on the energy-related raw-data derived by the RTMM. This context includes a) MMT-specific energy consumption values per interface state, b) energy-profile and residual PoA utilization time for various service types and c) delay, throughput and energy overheads introduced during past VHO execution phases. The two former may enhance the VHO energy-consumption evaluation basis, while (b) and (c) provide an appropriate time-horizon for VHO decision making and consistent QoS deterioration inference measures, respectively.

The VDE should be enabled to adjust the required level of context-awareness depending on a) the underlying heterogeneous network dynamics, e.g. network density and operating environment (urban, suburban, rural), and b) the current MMT status, e.g. battery drain rate and QoS requirements. For example, the energy-consumption evaluation basis can be built on mean energy consumption values per interface state, when on a rural environment with sparse network infrastructure. To further enhance the resulting performance when on urban environments with dense network infrastructure, CFM may alternatively provide the energy consumption per interface state as a multi-parametric function of the current PoA identity, current channel state, distance between the MMT and the PoA, and so on. As a result, a key criterion for concluding on the most suitable context derivation method should be the capability of dynamically adjusting both the detail and the accuracy of the derived context. Under this point of view, a comparative analysis on the efficacy and the adjustability of various machine learning algorithms [13] is required to conclude on the most suitable context derivation method on energy-related raw-data.

C. *Network Discovery Module*

The NDM is responsible for providing the VDE with an up-to-date list of all reachable and accessible PoA. The NDM list can be obtained either via autonomous MMT sensing or by incorporating network side information, e.g. from the Access Network Discovery and Selection Function (ANDSF) module under a 3GPP Long Term Evolution (LTE) architecture [14]. Although frequent sensing may increase the emerging energy-saving opportunities, it simultaneously introduces significant energy-consumption overheads at the MMT side. Thus, the adopted network discovery policy should weigh whether the resulting energy gain for utilizing a newly discovered PoA counterbalances the energy overhead introduced both due to the network discovery and the VHO execution procedure.

Under the proposed framework, the network discovery procedure is managed by the VHO decision engine. This management is in accordance with QoS-oriented and energy-efficiency NDM triggers, e.g. when the battery drain rate exceeds over a predefined threshold, or when the perceived SINR is constantly decreasing. These triggers may be either predefined/static or dynamically adjusted, by machine learning algorithms such as Q-learning [13]. A comparative analysis is necessary to conclude on the efficacy of various NDM triggers related to the battery drain rate, current location and the foreseen QoS deterioration. Further research effort is required towards appropriate machine learning techniques for dynamic trigger adjustment.

D. VHO Decision Engine

To resourcefully support the ongoing MMT services through the most energy-efficient PoA, the VDE should be built on the context-awareness introduced by both NDM and CFM modules. Under the proposed VHO framework, the role of the VDE is two-fold, i.e. a) access and evaluate accessible PoA alternatives and b) coordinate the energy-consuming network discovery procedure. In contrast with the current literature [4-6], both these operations are built on MMT-specific rather than fixed VHO-related context. The proposed VHO decision engine scheme is depicted in Fig.2.

The VDE coordinates the network discovery procedure by triggering the NDM on critical events such as high battery drain rate, channel state degradation, foreseen QoS-deterioration, and so on. These triggers constitute the adopted network discovery policy and can be either statically defined or dynamically adjusted by machine learning algorithms. A comprehensive policy should accommodate the energy-consumption during the network discovery procedure, the ongoing service QoS-requirements as well as the energy-consumption at the MMT side.

Upon a NDM list update, the proposed VHO decision scheme evaluates all PoA alternatives both in terms of offered QoS and energy consumption. In more detail, the VDE acquires auxiliary VHO context from the CFM regarding:

a. the current service characteristics in terms of energy-profile, service residual utilization time and QoS characteristics (max/mean/min bit-rate, delay and packet error rate tolerance, jitter, etc),

b. the current PoA characteristics in terms of perceived energy-consumption (channel state, distance, energy consumption per interface state, VHO delay and energy overheads) and offered QoS (current load, jitter, perceived delay)

c. the characteristics of all PoA in the NDM list, in terms of expected energy-consumption and offered QoS as above,

d. the user preferences in terms of allowed PoA, charging policy, security policy, etc.

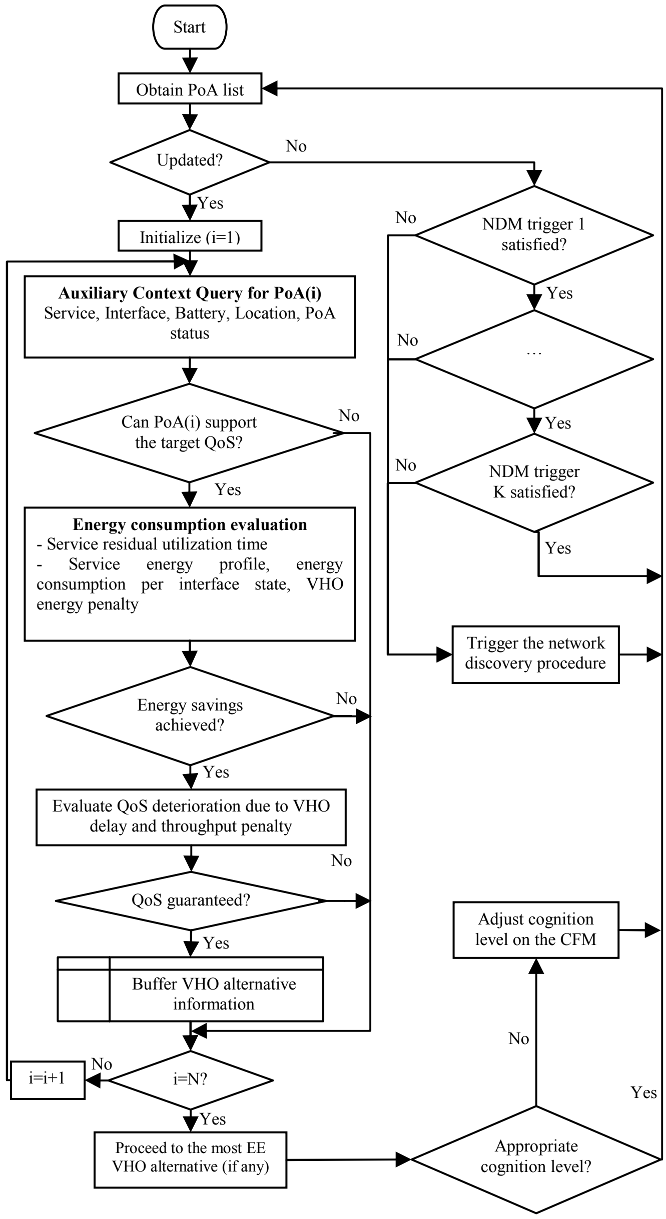

Figure 2: Proposed VHO decision scheme

Considering these, the VHO decision engine evaluates whether a tagged PoA alternative is capable of supporting the QoS-requirements of the current service. If so, an energy-consumption evaluation phase follows by taking into account the service residual utilization time, the service energy-profile (sojourn time per interface state), the expectations on the energy-consumption per interface state on the target PoA and the energy penalty introduced during a potential VHO from the current to the target PoA. If the energy-consumption evaluation tips the scale in favor of the tagged PoA alternative, the proposed VHO decision scheme evaluates the expected QoS deterioration due to the additional delay and throughput penalties introduced during the VHO execution phase. In case the introduced QoS degradation is tolerable, the tagged PoA alternative is buffered and the above procedure is followed for the remaining PoA on the NDM list. By the end of this procedure, the proposed scheme proceeds to a VHO procedure from the current to the most energy-efficient PoA in the buffer (if any). The VHO decision engine subsequently evaluates whether the detail and the frequency with which the auxiliary VHO contexts are derived, is appropriate. If not, the VDE adjusts the cognition level on the CFM, which in turn may suitably adjust the duration and the frequency of the real-time monitoring procedure.

The key features of the proposed VHO decision scheme can be summarized as follows:

1. Service and MMT specific VHO decision making by incorporating context-awareness.
2. Cognition level control by suitably adjusting the duration and frequency with which the energy-related parameters are derived.
3. Enhanced energy conservation by incorporating appropriate QoS and energy-efficiency triggers for the network discovery procedure.
4. Ping-pong effect diminishing by integrating the VHO energy, delay and throughput penalty in both the energy-consumption and the QoS evaluation basis.

IV. Conclusions And Future Work

Heterogeneous network selection in the context of energy-centricity is a challenging yet relatively unexplored area of research. Existing approaches are based on ambiguous assumptions on the required signaling procedure, their energy consumption evaluation basis as well as the consequential QoS deterioration due to the employment of the VHO procedure. This paper described a context-awareness framework capable of supporting energy-centric VHO decision making. The proposed framework consists of three auxiliary and one primary module. The RTMM monitors a wide-set of energy-related parameters residing on different protocol stack layers, the CFM integrates the derived cross-layer measurement raw-data to auxiliary VHO contexts, while the NDM senses the ambient heterogeneous network environment to obtain an up-to-date list of all accessible PoA. The VHO decision engine role is two-fold, a) to access and evaluate accessible PoA alternatives and b) to appropriately coordinate the energy-consuming network discovery procedure.

The adopted energy consumption evaluation is based on MMT-specific energy consumption values per interface state and service-specific energy-profile, in terms of sojourn times per interface state and residual utilization time. The additional VHO delay, throughput and energy overheads are integrated into the energy consumption evaluation basis to accurately predict a potential QoS deterioration and diminish the ping-pong effect. Further energy-savings can be derived by suitably adjusting the policy-driven network discovery triggers and the context-awareness level on CFM.

Future work includes a) comparative analysis towards suitable context derivation methods on energy-related raw-data, b) comparative analysis on the efficacy of various NDM triggers and appropriate machine learning techniques for dynamic trigger adjustment, c) a detailed energy-consumption and QoS deterioration evaluation basis and d) extensive simulation results and case studies on the adaptability and the efficacy of the proposed VHO framework under various RAN technologies.

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