Context Parameter Prediction to Prolong Mobile Terminal Battery Life

Muhammad Alam, Michele Albano,
Ayman Radwan, and Jonathan Rodriguez

Instituto de Telecomunicações (IT - Aveiro)
Campus Universitário de Santiago, 3810-193 Aveiro, Portugal
{alam,michele,aradwan,jonathan}@av.it.pt

Abstract. Energy is a critical resource for mobile devices, which depend on batteries for power supply. With the high energy requirements of the new wireless generation, there is a definite need for new techniques for power saving. The C2POWER project is an European project having the goal of implementing energy-saving techniques for multi-standard Mobile Terminals (MTs). The main techniques used by the project are inter-technology handovers, which are known as Vertical Handovers (VHOs) and cooperation among MTs. Modern computing systems are harvesting the techniques of context aware computing to work towards different goals. This paper describes a way of using context information to enhance the energy saving capabilities of MTs. This paper proposes a structure for the context parameters, the architecture for context information management, and the context prediction framework. The paper focuses particularly on the MT cooperation scenario, and shows how to implement energy saving in a scenario, where MTs have control over the value of the energy they are willing to spend to relay traffic for other MTs, as well as the price they accept to pay.

Keywords: energy saving, context history, cooperative relaying, VHO.

1 Introduction

The C2POWER project [1] aims at leveraging on two different techniques to decrease energy consumption in Mobile Terminals (MTs). In particular, the MTs being considered are advanced devices, that are capable of using advanced mobile applications (multimedia, videoconferencing, online gaming, movie ...). The techniques used by C2POWER are shown in Figure 1, and concentrate on two folds:

- Vertical Handovers (VHOs) between heterogeneous Radio Access Technologies (RATs)
- Cooperative relaying between MTs

C2POWER approach can be placed into the broad category of cognitive networks. The current directions usually focus on the use of cognitive networks

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for spectrum efficiency. C2POWER, on the other hand, targets the problem of energy saving using cognitive networks, which, until now, has been scarcely addressed in the literature. Both VHOs and cooperation between MTs can help the system achieve longer lifetime and system efficiency. In this sense, C2POWER has to use context information to make informed decisions about the actions that can be taken to improve the system efficiency.

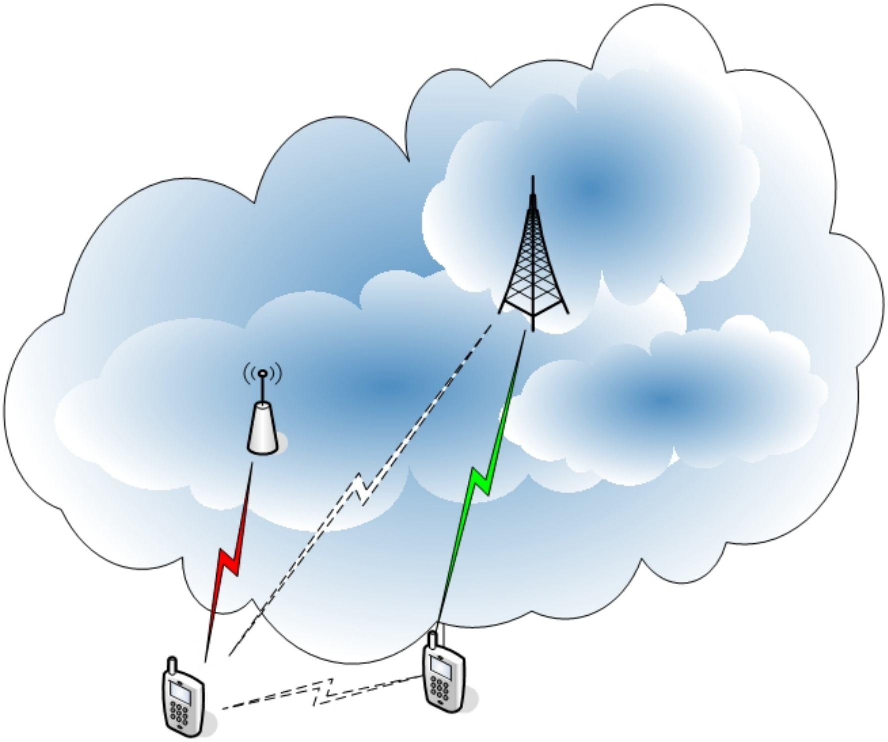

Fig. 1. Options for C2POWER enabled terminals: the left one can switch from one long-range connection (red link) to either a more energy-efficient RAT (Vertical Handover) or have another terminal relay its packets (short range cooperation)

C2POWER's approach for energy saving is shown in Figure 1. The terminal on the left is considering to switch from one high energy consuming connection (red link) to either another RAT using direct connection via VHO or have another terminal relay its packets (short range cooperation).

This paper presents a structure for context parameters that can be collected and used. The paper explores the usage of user's history to predict its future context parameters (energy levels, needs of energy, etc), and finally it introduces a proposal about tweaking the price of energy of MTs based on their current perception of the value of energy.

The rest of the paper is organized as follows. Section 2 presents related work; section 3 proposes a structure for the context information managed by the system; section 4 describes an architecture that can be used to manage the context information; section 5 focuses on the prediction of context information to enhance the power saving capabilities of the system; section 6 presents some insight about the value of energy perceived by MTs, and finally section 7 concludes the paper.

2 Related Work

2.1 Cognitive Radio and Cooperative Communication

Recently, cognitive radio and cooperative communication have been addressed in several projects funded by European Union (EU). Several research projects have been proposed to investigate the spectrum utilization for wireless and mobile communication systems. COGEU is one of the most recent projects to study cognitive radio. The goal of COGEU is to implement enabling technologies based on cognitive radio to support mobile applications over TV white spaces making use of the TV digital switch-over [2]. The ORACLE project [3] investigates mechanisms and architectures for cognitive radio networks and terminals, aiming to demonstrate the socio-economical advantages of opportunistic spectrum usage. Another project – SENDORA [4] – looks into novel spectrum sensing techniques to identify spectrum holes. In addition, information management and exploitation are studied to achieve the co-existence of cognitive radios within licensed spectrum bands. CODIV [5] aims to develop and optimize combinations of physical and network diversity to increase network capacity, robustness and fairness. ARAGORN [6] investigates enabling technologies that facilitate the application of machine intelligence and adaptive communications technologies in the optimisation of resource usage in wireless networks. The developed technology addresses the issue of increased system complexity of reconfigurable and software radio based devices and also enables cooperation between smart objects. COOPCOM project aims to advance the state-of-the-art of cooperative and opportunistic communications, focusing on relay protocols for coverage extension [7].

Cognitive radios have been extensively studied, for the purpose of enhancing spectrum efficiency, exploiting the concept of opportunistic radios and spectrum pooling. Cooperation has also been considered only for improving wireless link capacity or coverage extension. Despite the extensive studies on cognitive radios and cooperation between MTs, these two disruptive emerging technologies have scarcely been used for the purpose of energy saving.

2.2 Energy Saving and Green Technology

There is no formal definition of "green" in networking because there are several issues spanning different layers from physical to application that need to be addressed to achieve green networking. Green practices are still young and can be best described as the integration of technologies and mechanisms to improve energy efficiency at all layers. For cellular networks, femtocells are known to greatly reduce the energy consumption. The impact of deployment strategies on power consumption has been presented in [8]. Layouts featuring an area power consumption as a system performance metrics have been used. Several researches have addressed cross-layer approach for energy efficient design to take advantage of features in different layers. In [9], the authors present a comprehensive overview of recent advances in cross-layer design for energy-efficient wireless communications. The focus is particularly on system-based approaches toward energy optimal transmission and resource management across time, frequency, and spatial domains. A significant amount of power is consumed at the network, so considerable research has been devoted to the low-power design of the entire network protocol stack of wireless networks. A study of recent work addressing energy efficient and low-power design within all layers of wireless network protocol stack have been presented in [10]. A new concept called "bits-per-Joule capacity", which is the maximum total number of bits that the network can deliver per Joule of energy deployed into the network has been introduced in [11].

Energy efficient operation of cellular networks requires a holistic view of redesigning the network from components to network subsystems, algorithms, protocols, and deployment strategies. An overview of such techniques can be found in [9].

EARTH, an EU funded project, plans on tackling the issue of green communication through the development of a new generation of energy efficient equipment comprising components, deployment strategies and network management solutions [12]. The EARTH project focuses on the energy efficiency of mobile broadband systems, thereby contributing to the reduction of CO_2 emissions.

2.3 Context Awareness

Alternative views applied to "context" lead to different definitions and different levels of applicability. An application-centric definition that is more suitable for problem solving and system design is: "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between the user and the application, including the user and the applications themselves" [13]. The definition states that context is always bound to an entity and that information describing the situation of an entity is context, including the task itself. Other authors agree that user's actions are generally goal-driven and hence the activity of the user (defined as a set of simultaneous tasks) becomes central to the user context [14].

The term context-aware appeared in [15] for the first time, where the authors described context as "location, identities of nearby people, objects and changes to those objects" [16].

Many EU projects have explored context-awareness aspects, specially focusing on context capturing and context reasoning. Examples of which are MobiLife [17], SPICE [18], and OPUCE [19]. Integration of context aware systems with mobile multimedia delivery technologies are explored in [20]. The numerous platforms and solutions, described in the literature, still fail to offer a flexible, generic solution. Service and delivery integration with context management continues to be a challenging research area.

Based on the survey of the related work, it can be seen that cognitive radios and cooperation have been extensively studied. On the other hand, many researches and projects are investigating context aware functionalities. Despite all the above efforts, there is little work towards the application of the emerging techniques for the purpose of energy saving and green communication. The main innovation of C2POWER project is to combine cognitive radios which are context aware enabled with cooperative strategies, for the sake of power saving in the communication part of MTs to extend their battery lifetime.

3 Context Parameters Structure

This section describes the structure of the context information that is considered by a C2POWER-enabled MT and Network to improve energy saving capabilities of MTs during the execution of their applications. The contexts used have been broadly categorized as **Network contexts**, and **MT contexts**.

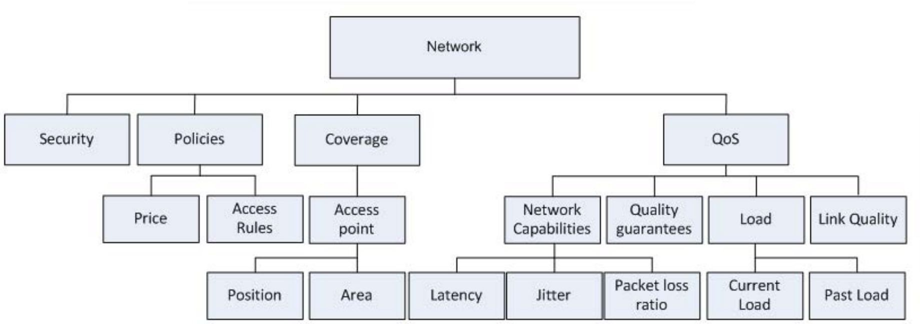

Fig. 2. Context structure for the contexts owned by the network

3.1 Network Contexts

There are four categories of network context information that are taken into account by the context management system.

Security defines the security level of the network access, that is fundamental to the user to decide whether he is interested into accessing the RAT; moreover this set contains the type of security mechanism the network is using, since this information can facilitate a VHO towards the RAT. Security context is set by the network operators when the network is deployed.

Another context information, which is set by operators and rarely modified, belongs to the **policies** category. It depends mainly on agreements between the end-user and the access provider, and on agreements between different operators. This context information is about the **access rules** regarding a given network for a user registered with another provider, and the **price** charged for accessing the network. The information gathered can be utilized in the business model or in price based preferences for VHO.

The category of **coverage** comprises more elements that are usually static, and it provides the information about the coverage of the network and the co-existence of different networks. In particular, this data contains **access point** parameters, which are used to infer the different networks covering certain locations.

Both static and dynamic data exist in **QoS** context category, that describes the maximum and current capabilities of the network. Static aspects regarding QoS are related to the maximum **network capabilities**, like for example the latency and bandwidth related to the technology for internet access, and the **quality guarantees** that the network can provide by using resource reservation protocols. The QoS that can be provided at a given time depends mostly on the current **load** of the base station. Hence the context module maintains both *current load* and *load history*. Using the logs about past load, the context module can perform some level of load estimation for the time the MT wants to be relayed, as shown in section 5. Another dynamic information used to evaluate the QoS provided by the network is the **link quality** of the connection between the MT and the network, that can be expressed by RSS, CIR, SIR, BER, etc.

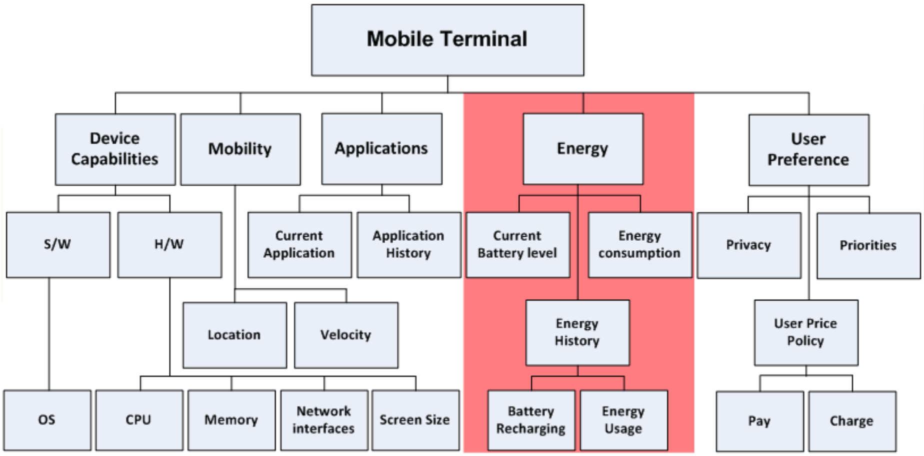

Fig. 3. Context structure for the contexts regarding the Mobile Terminal

3.2 Mobile Terminal Contexts

Five categories of MT context information have been identified.

Context information about **device capabilities** is composed of data describing the device itself, comprising both **hardware** and **software** (*CPU, Operating System, Memory, Display Capabilities*), with a particular focus on the *network interfaces*. These data are usually constant over time.

Most of the other context information change over time. **Mobility** context provides information about the current **location** of the MT and its **velocity** (comprising speed and direction of mobility). This information is used to predict future location of MTs, and can be used to determine if a given VHO or short-range cooperation can be useful for energy saving. Moreover, a network can also use this context information about MT mobility to predict its own load, based on MT going in and out of its coverage.

The **application** category contains information about applications currently in use by MT (**current application** in the figure), which determine the QoS requirements. Moreover, a log of **application history** is maintained, to profile the common use of the MT, and predict the behavior of the user on short term basis.

The system we describe focuses on energy saving, and in fact an important set of context information regards the energy of the MTs. The **energy** category comprises the **current battery level**, the rate of **energy consumption**, and **energy history** of the terminal. Energy history provides quantitative data on energy usage at different times of the day and the frequency of battery recharging. The energy information is used to predict the user needs for energy on the short and medium terms.

The last category of context information is **user preferences**, which are a set of parameters that are defined by the user, to specify what the user wants or expects from its interaction with C2POWER-enabled system. The user can set his **priorities** to be energy saving, price minimization or performance maximization. These user preferences can be a complex structure that bears data for different scenarios. For example, even for a user mainly concerned with energy saving, his priorities can be considered to be temporarily shifted to "performance maximization" if the user is executing an emergency call. Another issue considered in user preferences is the **privacy** that is desired by the user. In fact, some parts of the context information are used to profile the way the MT is used, to be able to predict the future needs of the user, and this implies logging data about user behavior. Hence there is a trade-off between user's privacy and the prediction capabilities of the system, that would not be able to function at full power without collecting data about the user behavior. Finally, the user can select a different profile for the **user price policies**, to decide how much the user is willing to *Pay* during energy saving collaboration, and how much money/privileges the user will *Charge* to relay other MTs' traffic. This information sets two profile functions, since the quantity of money the user is willing to pay or wants to receive depends on how much the user values its own energy, which depends on the current energy level and the prediction of the user behavior regarding future usage and battery recharging in the short term.

4 An Architecture for Context Management

This section presents an architecture that can be used for context management to implement the goal of energy efficient vertical handovers and mobile terminal cooperation. Figure 4 presents the architecture that is deployed on both the MT and the network.

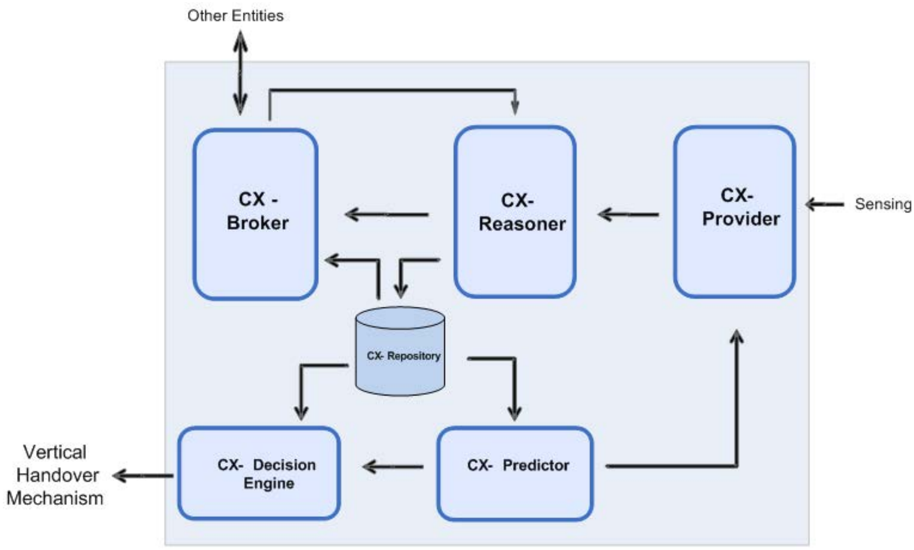

Fig. 4. Architecture for context management, for both mobile terminal and network

The **CX-Provider** is the entry point for context information into the system. In particular, it is in charge of providing to an entity (MT or Network) all the information that is not transmitted from another entity. Data is in raw form (unprocessed) for the CX-Reasoner to process. The way this component interacts with the rest of the system depends on whether it is deployed on the Network side or on a MT. An MT gets input from MT's sensing units, and from internal databases keeping track of user preferences, while a Network gets data from the policy database of the operator, and directly from the uplinks of the MTs. Output from CX-Provider is initiated when there is a change in state. The CX-Provider then provides data to the rest of the system through the CX-Reasoner.

The **CX-Reasoner** filters/processes/aggregates the raw data it receives from the CX-Provider regarding the entity (MT or Network) it is deployed on. The CX-Reasoner also receives data about other networks and other mobile terminals from the CX-Broker. The CX-Reasoner produces high level information, that is then stored in the CX-Repository for future queries, and also forwarded to the CX-Broker to be sent in real time to other MTs and Networks that subscribed data.

The **CX-Broker** mediates the interactions between different MTs and networks, interacting with other units' CX-Brokers with the goal of exchanging context-related information. CX-Broker gets data via one-time queries to the CX-Repository and to other entities's CX-Brokers, and also directly from the CX-Reasoner and via subscriptions to other entities' CX-Broker according to a publish/subscribe paradigm. The collected data is then provided to the CX-Reasoner of the MT or network.

The **CX-Decision Engine** uses the context information to take decisions, that can be Vertical Handovers or multi-MTs cooperation, with the goal of implementing an efficient energy saving. It accesses context data from CX-Repository via queries. The output of CX-Decision Engine consists of suggestions about VHO and multi-MTs collaboration.

The **CX-Repository** stores the processed information that is received from the CX-Reasoner. The CX-Repository is then accessed via queries, by the CX-Broker that sends processed data outside, and by the CX-Decision Engine that uses the processed data to support decisions.

Finally, the **CX-Predictor** provides prediction about future context status. In the case of MTs, predictions can be about future battery level and future location information. In the case of Networks, this component predicts location information for disconnected/power-saving MTs, and the network load that will be faced in the short and medium terms. The CX-Predictor gets the information processed by the context reasoner via queries to the CX-Repository. The output of the CX-Predictor supports the CX-Decision Engine in its decision making, and predicted data can be routed through CX-Provider to be filtered/processed/aggregated with other data.

5 Prediction of Context Parameters

The goal of C2POWER is to extend the lifetime of MTs, by improving their energy usage, while providing the QoS required by the applications in use. Given a set of active MTs connected to RATs, C2POWER determines which ones perform VHO towards different RATs, and which ones get their traffic relayed by other MTs, with the goal of energy saving.

Energy saving is implemented because, first of all, some of the MTs can be in better positions to communicate directly with base stations; moreover, if a MT has got a lot of battery energy, it can support the communication of MTs that have a depleted battery, hence increasing the lifetime of the network. It is possible to leverage on the knowledge of context parameters to predict MT conditions, as shown in subsection 5.1.

On the other hand, using context parameters can lead to an energy cost more important than the energy saving realized. A useful technique to cope with this potential energy waste is to use context parameter prediction to "extrapolate" based on the sampled set of context values. Subsection 5.2 analyzes the problem of energy waste for context data transmission, and proposes a technique to cope with this issue.

5.1 Predicting Context Information by Profiling

Different MTs (different users) make use of a different set of applications, hence it is not possible to globally consider all MTs in the same way. Some users will make heavy use of videoconferencing and advanced multimedia applications, while others will only make phone calls and exchange SMS. The best option is to have the MTs that have surplus energy to use their energy to relay the MTs having energy shortage.

Thus, a short-sighted energy management strategy can be detrimental to the MTs. For example, a simple scheme could always be to enforce MTs with higher current battery level to spend energy to relay traffic of MTs with less energy. On the other hand, in some cases a higher energy level is related to a more expensive mobile equipment, owned by a user that makes more use of advanced multimedia application and hence needs more battery energy than other users.

Even though every MT has potentially a different behavior, it should be pointed out that people are prone to respond to given behavioral patterns. For example, a user could only use the telephone for SMS and phone calls, while another one could often access online games, and others could perform videoconferences frequently. In this model, it is possible to predict the pattern of application usage, and battery level from the past history of the MT.

Logging the history of the MT, in terms of used applications, battery level, and user location, can enable the C2POWER system to predict if and when the MT will need its own energy, where the MT will be, and hence whether the MT can be more interested in acting as a relay or in being relayed by other MTs, as well as the MT's possibility of being handed over to a cheaper RAT.

One more issue that must be dealt with is related to the privacy setting of the user, and its impact on the context prediction accuracy. If the user desires a high level of privacy, the MT will not log the user's activity, battery level and location, hence the prediction system will have less information to build a prediction and facilitate the MT's energy saving. From this point of view, it is possible to identify a trade-off between prediction capabilities and privacy levels.

On the Network side, a useful prediction on the future load of the network can be used to decide whether the Network will be able to support the QoS needed by MTs. It is possible for the Network to collect data regarding its own load, and use them to profile the load level. Usually, the usage pattern of a base station repeats itself over time, hence the Network can know if it is going to have a large number of users in the next few hours.

When a MT starts the VHO procedure the Network can provide information about the predicted QoS it can support based on predicted network load. Hence the MT can decide whether to perform the VHO to the Network based on the MT's current and future QoS needs.

5.2 Predicting Context Information by Extrapolation

Another problem that regards the use of context parameters is about the collection of context data, since for some of the context information, it implies a wireless transmission from the MT to the network, and vice versa.

An inspection of Figure 3 was the first step towards a comprehensive analysis of this potential problem. The context parameters that are prone to this issue are not the ones regarding the use of **applications**, since they can be communicated during the application lifetime and hence their transmission would represent a negligible energy cost when compared to the application cost. The **user preferences** and the **device capabilities** are mostly constant, and therefore their communication does not constitute a problem.

On the other hand, parameters related to **mobility** and **energy** can waste energy, since they can change often and it is possible that the C2POWER system needs to refresh this information while the MT is in its *power saving* state. When the MT is using the network, it is already consuming energy to synchronize itself and in general to be part of the network, hence sending context parameters' data is not a problem. Moreover, the quantity of data to be sent is quite limited. In the case of **mobility**, for example, it can be a few bytes specifying the coordinates of the MT in a GPS coordinate system. In the case of **energy**, a few bytes are enough to flush the energy level of the unit in the last few hours.

When the MT is not communicating with the network, the setup of communication would represent an obstacle to the energy saving capabilities of the *power saving* state. The approach that we propose is to use context parameters' prediction to extrapolate the MT state between subsequent context collections, with the general goal of having a good representation of the MT state while performing a lower number of context parameter transmission.

Considering the *Mobility* parameters, we propose to use information about both application usage pattern and user mobility pattern, to be able to infer where the user is located. For example, from the logs about user activity, we can be able to infer that in the night, if the user is not using any application and it has been static for some time, the user will probably stay static for the rest of the night, hence as long as the MT is not using applications we can lower the frequency of context parameter collections. In general, for *Mobility* parameters, context prediction can be used to lower the frequency of context collection when we are able to profile the user to know that it is not moving. This energy saving strategy is based on the hypothesis that user mobility patterns tend to be constant over time, and corroborated by recent research on user mobility patterns [21].

Let us now consider the *Energy* parameters, and how we can limit the energy used for data transfer from the MT to the network. When an MT is not executing any application that involves communication with the Network, the MT is in its *power saving* mode, and it is consuming energy at a slower pace. On the other hand, the MT has to temporarily switch to *active* mode, spending energy, to send information to the Network. Thus, it is reasonable that energy data is sent less frequently while the unit is in a *power saving* mode. Moreover, the unit could cache its energy data into its flash memory, collecting its battery status over time. The energy data would be flushed to the network when the MT starts an application that causes it to connect to the Network. In the meantime, the

Network can compute a conservative prediction of the MTs' energy value, by assuming that the MT is in *power saving* mode.

Moreover, whenever data about MT's energy level reaches the network, it also bears information about important events related to energy. If the energy used per time unit is lower than average usage, the network can deduce that the unit was switched off or in *power saving* mode. If the energy value is larger than the last reported value, the MT was being charged. All these data can be used to draw a profile of the user, infer its energy usage pattern, and predict if he is going to need more energy in the short-term, or if he is a candidate for relaying other MTs' data.

A way of managing the *Energy* parameters is presented in section 6, where energy data is not sent explicitly to the network. In that paradigm, data about user preferences and prediction about energy level and energy needs are composed and used to modify the price the users are willing to pay to MT relaying their traffic, and the price they charge to relay other users' traffic.

6 Cost of Energy

From the discussion of section 5, it is clear that different users have different demands concerning energy management.

One possible implementation of such demands is done performing the tuning of the "Quotes for Energy". If the user will shortly need the energy, his energy will be more valuable for him. On the other hand, a user planning to recharge his MT's battery soon, would be more willing to relay other units' traffic, if he is compensated.

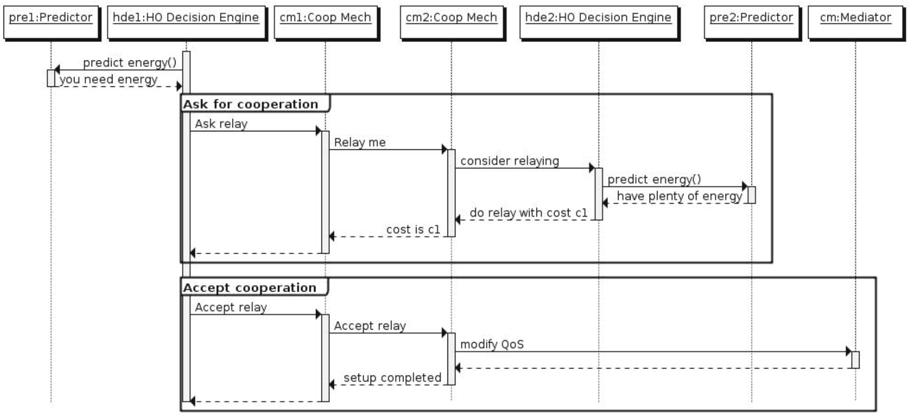

Fig. 5. Terminal 1 needs to save energy, and it sets up a cooperation with terminal 2, which will relay its packets

One mechanism to implement this vision is “Quotes for Energy”. The “Quote for Energy” mechanism allows the modification of the price of energy in terms of money, privileges or compensation, based on the preferences of the user. The composition of energy level prediction, energy needs prediction and user preferences leads to the computation of two values. The first value is the price that is charged for relaying other users’ traffic, the second value is the maximum price that is offered to a relayer. If a user charges a price that is lower or equal to the price that another user is willing to pay, a collaboration between their respective MTs may occur.

Figure 5 shows an example of message exchange between MTs, when they are checking if they can build a collaborative cluster. The users find a deal, hence one of the MT sacrifices its own enery to let the other units have a longer lifetime, for a price.

7 Conclusions

Advanced wireless MTs have ever increasing power requirements, which are not matched by the slow advancing battery industry. There is a need for new technologies for power saving, if MTs are to take advantage of the advanced services offered by wireless networks. This paper considers the issues of leveraging on context information to enhance the energy saving capabilities of MTs, by presenting some of the features of the EU project “C2POWER”. In particular, we propose a structure for the context parameters that are taken into account by the system, considering context information related to both Networks and MTs. We describe a functional architecture for the collection and management of context information. Context information prediction is also introduced to foresee whether a user should relay other users’ traffic, depending on predicted future energy consumpion and future energy needs. Finally, we consider a cooperation setup in a free market about energy, introducing the “Quotes for Energy” mechanism.

Future work will consider how to integrate the proposed architecture into the C2POWER system. The context management system would interact with the mechanisms that enable the actual VHO and cooperation, with the goal of saving energy. The realization of an energy market, to be used in the “Quotes for Energy” mechanism, remains an open issue. A mathematical analysis is required, which uses game theory concepts, to realize a “Limited Visibility Auction”: energy is traded, but the buyers and sellers limit their offers to their neighbors in the connectivity graph.

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