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D3.5 Version 2.1

Energy efficient discover mechanisms of candidate networks and neighbour nodes - final version

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Abstract:

This deliverable provides detailed description and extensive performance evaluation results of the energy efficient network and node discovery mechanisms proposed and developed in within the scope of C2POWER project. C2POWER is a project that aims at using short range cooperative communications and heterogeneous vertical handovers to reduce the energy consumption of wireless devices. Cooperative communications and vertical handovers require efficient discovery mechanisms, which are usually time and energy consuming. C2POWER project proposes novel energy efficient node/network discovery mechanisms, using context information available for network and mobile devices. More specifically, the proposed energy efficient network discovery algorithm resides at the mobile terminal and takes into consideration user and network context information in order to decide on the most appropriate time to perform a network scan, avoiding unnecessary network scanning and misdetection of available networks that can be used as targets for handover. Similarly, the proposed node discovery algorithm addresses the issues of excessive scanning and synchronisation in an energy efficient manner, based on the formation and exchange of context information lists of the available short range networks. Detailed description of both mechanisms are provided in the document. The performance of the proposed discovery mechanisms is evaluated through extensive simulations. The presented simulation results show the energy saving gains in the discovery mechanisms, highlighting the avoidance of unnecessary scanning, the decrease in misdetection and the lower delay in accessing available networks or joining available cooperative clusters.

Keyword list: Access Network Discovery and Selection Function, context awareness, network discovery, node discovery.

Executive Summary

C2POWER project aims at reducing the energy consumption of wireless mobile devices, by exploiting the multiple interfaces of the devices through short-range cooperative communications and smart vertical handover between heterogeneous Radio Access Technologies (RATs). Multiple interfaces can be efficiently used to save battery power of mobile devices, by keeping mobile devices always connected to the network with the least energy consumption requirements, or through using multihop short range relaying to reach infrastructure based RAT. On the hand, if not carefully controlled, multiple interfaces can become an energy burden on the mobile devices. Towards this end, C2POWER proposes to carefully and efficiently manage the multiple interfaces to reduce the energy consumption of the wireless mobile devices, by deciding which RAT to connect to or to exploit short-range cooperative relaying.

The big burden in C2POWER approach is that using multiple interfaces would increase the energy consumption of mobile devices due to continuous power drain of multiple interfaces, as well as the continuous scanning of non-connected interfaces; hence C2POWER needs to smartly manage those multiple interface to benefit from the good energy consumption rate they offer, while avoiding the unnecessary draining of power, when not in use.

The C2POWER depends on one main enabler to achieve the promised energy saving strategies. This enabler is the availability of context information that can accurately model the surrounding environment of the mobile devices. Workpackage (WP3) of C2POWER is the workpackage responsible for providing the required context information for proper functioning of the energy saving strategies, as well as proposing, designing and evaluating novel energy efficient node and network discovery mechanisms.

WP3 is divided into three main tasks: T3.1. Identification of context parameters; T3.2. Energy efficient discover mechanisms; and T3.3. Context aware module implementation.

Task T3.1 identified all the context parameters, which can be useful to save energy exploiting short range cooperative communications or cognitive vertical handover. The parameters were classified into main categories: Network context information and node context information. All categories were further categorized into multiple categories. The identification and classification of context parameters were earlier reported in C2POWER deliverable D3.1 [1]. Those categories are briefly visited in the current deliverable "C2POWER D3.5".

Task T3.3 describes in detail the specification and implementation issues of the context aware modules of the C2POWER functional architecture. The outcome of Task T3.3 is provided in C2POWER deliverable D3.4 [2]. The deliverable presents detailed definitions of the interactions that take place between different modules of the context support architecture of C2POWER, as well as the implementation specifications of the different elements of the context awareness functionalities.

Finally, task T3.2 addresses the issues of energy wasting due to node or network discovery. It is well known that node or network discovery processes can be trivial and high energy consuming; hence, T3.2 proposes energy efficient node and network discovery mechanisms to overcome this energy burden by the aid of context information. The final work and evaluation of the proposed mechanisms are provided in the current deliverable C2POWER D3.5.

Deliverable D3.5 is the fifth and final deliverable of C2POWER WP3, documenting how the objectives of task T3.2 on the provision of energy efficient discovery mechanisms are fulfilled. It provides detailed description and extensive performance evaluation results of the final versions of the energy efficient network and node discovery mechanisms.

The deliverable summarizes the role and potential for energy consumption minimization of the network and node awareness in C2POWER. More specifically, a brief overview of the components and interfaces that constitute the C2POWER architecture is provided, emphasizing the components that are responsible for the network and node discovery procedures. Additionally, the main categories of network and user context information are briefly described giving an appreciation of the importance of context awareness in energy consumption minimization.

The deliverable describes in detail the proposed energy efficient network discovery mechanism, which utilizes information on the user location and the availability of neighbouring networks in order to decide the most appropriate time to perform a network scanning and discover available networks that can be used as targets for handover. Based on extensive performance evaluation results, it is shown that the proposed network discovery algorithm allows the reduction of energy consumption, as well as the considerable improvement in the network detection delay with no compromise in the network detection rate.

Finally, the proposed energy efficient node discovery algorithm is presented. The algorithm addresses the issues of node discovery and cooperative cluster formation in an energy efficient manner. More specifically, a heterogeneous Worldwide Interoperability for Microwave Access (WiMAX) – Ultra Wideband (UWB) networking environment is considered, where mobile nodes exchange context lists that contain information that allows them to take efficient decisions regarding cluster formation. A mathematical model is used to calculate the average number of node discovery attempts and demonstrate the potential of the proposed algorithm for energy consumption reduction. Simulation results are provided to show the energy saving achieved with the use of the context based discovery process.

The deliverable concludes the work performed within WP3 of C2POWER “Context Awareness and signalling for power saving strategies”. The Workpackage has provided a list of context parameters, which can be useful for energy saving techniques, and classified them into different categories. The Workpackage also presented a context awareness architecture module, which can be adopted for providing context awareness in general (not only for the purpose of energy savings). The work has summarized the implementation issues with regards to the proposed context aware architecture. Moreover, the efforts in WP3 have resulted in proposing two energy efficient discovery mechanisms (one for node discovery and another for network discovery). The two mechanisms show significant energy saving gains, when compared to traditional continuous or periodical scanning mechanisms.

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List of Acronyms and Abbreviations

Term	Description
3GPP	3rd Generation Partnership Program
AGPS	Assisted Global Positioning System
ANDM	Access Network Discovery Module
ANDSF	Access Network Discovery and Selection Function
AP	Access Point
AWGN	Additive White Gaussian Noise
BL	Battery Level
BLth	Threshold Battery Level
BP	Beacon Period
BS	Base Station
CM	Cooperation Module
DRP	Distributed Reservation Protocol
DTP	Data Transfer Period
EPC	Evolved Packet Core
IE	Information Element
LTE	Long Term Evolution
MAC	Medium Access Control
MAS	Medium Access Slot
MT	Mobile Terminal
NDI	Network/Node Discovery Information
NDM	Network Discovery Module
PCA	Prioritized Contention Access
QoS	Quality of Service
RAT	Radio Access Technology
TDMA	Time Division Multiple Access
UE	User Equipment
UWB	Ultra Wideband
WiMAX	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WP	Work Package

1. Introduction

Deliverable D3.5 is the fifth and last deliverable of Work-package 3 (WP3) of C2POWER project. It describes in detail the proposed network and node discovery mechanisms and provides documentation on the simulation based performance evaluation of the energy efficient network and node discovery mechanisms of task T3.2.

The second deliverable of WP3 of C2POWER, D3.2 entitled “Energy efficient discover mechanisms of candidate networks and neighbour nodes – initial version”, provided an overview of node and network discovery techniques and highlighted the importance of network and node awareness in the context of the C2POWER energy saving strategies. The respective requirements and limitations, as well as the main functionalities required for the implementation of the network and node discovery procedures were also described.

This deliverable is the continuation and final version of the deliverable D3.2, and provides detailed descriptions and extensive performance evaluation results of the final versions of the energy efficient network and node discovery mechanisms that are designed and implemented within the scope of C2POWER project.

In section 2, a brief summary of the role and potential for energy consumption minimization of the network and node awareness in C2POWER is provided. More specifically, the components and interfaces that constitute the C2POWER context awareness architecture are described, emphasizing on the components that are responsible for the network and node discovery procedures that are of interest in this deliverable. Additionally, the main categories of network and user context information that provides the different modules with the necessary awareness of the surrounding environment, in network and terminal level, and allow them to efficiently adapt their operation towards the goal of energy consumption minimization, are briefly described.

Section 3 describes in detail the proposed energy efficient network discovery mechanism, which utilizes information on the user location and the availability of neighbouring networks in order to determine the appropriate, in terms of energy efficiency, time to perform a network scanning and discover available networks that can be used as targets for handover. Based on simulations that compare the performance of the proposed algorithm with different periodic network discovery schemes, it is shown that the proposed network discovery algorithm allows the reduction of the energy consumption, as well as the considerable improvement of the network detection delay with no compromise on the network detection rate.

In section 4, the proposed energy efficient node discovery algorithm is presented. The algorithm addresses the issues of node discovery and cooperative cluster formation in an energy efficient manner. More specifically, in a heterogeneous WiMAX – UWB environment mobile nodes exchange context lists that contain information that allow them to take efficient decisions regarding cluster formation. A mathematical model is used to calculate the average number node discovery attempts and demonstrate the potential for energy consumption reduction of the proposed algorithm. Extensive simulation results are provided to show the energy savings achieved with the use of the context based discovery process.

Finally, section 5 provides a summary of the described mechanisms, as well as concluding remarks.

2. Network and Node Awareness in C2POWER

The aim of C2POWER is to allow modern mobile communication terminals to take advantage of the availability of multiple wireless interfaces and the presence of neighbouring devices willing to establish cooperation in order to reduce their energy consumption. To this end, WP3 is responsible for the design, implementation and validation of energy efficient network and node discovery mechanisms through the establishment of a context awareness support architecture. More specifically, the knowledge of the available context in terms of neighbouring network and node availability is considered by the C2POWER architecture in two ways. First, in the case of vertical handovers, energy consumption minimization is achieved through the deployment of energy efficient network discovery and selection mechanisms that allow the mobile terminals to optimize the network discovery procedures and, finally, select the network type that satisfies their requirements. Similarly, the mobile terminals are allowed to adopt cooperative communication approaches, according to which they can identify neighbouring nodes that can act as relays, enabling the formation of appropriate clusters to allow the reduction of communication energy consumption.

Figure 2.1 depicts the components and interfaces that constitute the C2POWER context support architecture, categorizing the identified modules based on their logical location. Therefore, the different context awareness support functions reside either on the network or on the terminal side of the C2POWER architecture. On the network part, the Network Discovery Module (NDM) is responsible for the network discovery procedure, by performing the collection and provision of information on the available unknown or non-registered networks. On the terminal part, the modules that are responsible for the network discovery procedure are the Access Network Discovery Module (ANDM), which provides the information required to achieve awareness of the network environment, and the Network Discovery Module (NDM), which uses information on terminal settings and available nodes in order to make targeted searches for available access networks. Node discovery is the responsibility of the Cooperation Module (CM), which uses terminal context information to search for and negotiate with neighbouring nodes in order to implement multi-hop collaboration policies. Moreover, the Network/Node Discovery Information (NDI) module is responsible for collecting and refining information on networks or nodes in the terminal neighbourhood that can be used as access points or relays, respectively. A detailed description of all the components of the C2POWER architecture and the specification of the interfaces for their communication can be found in [2].

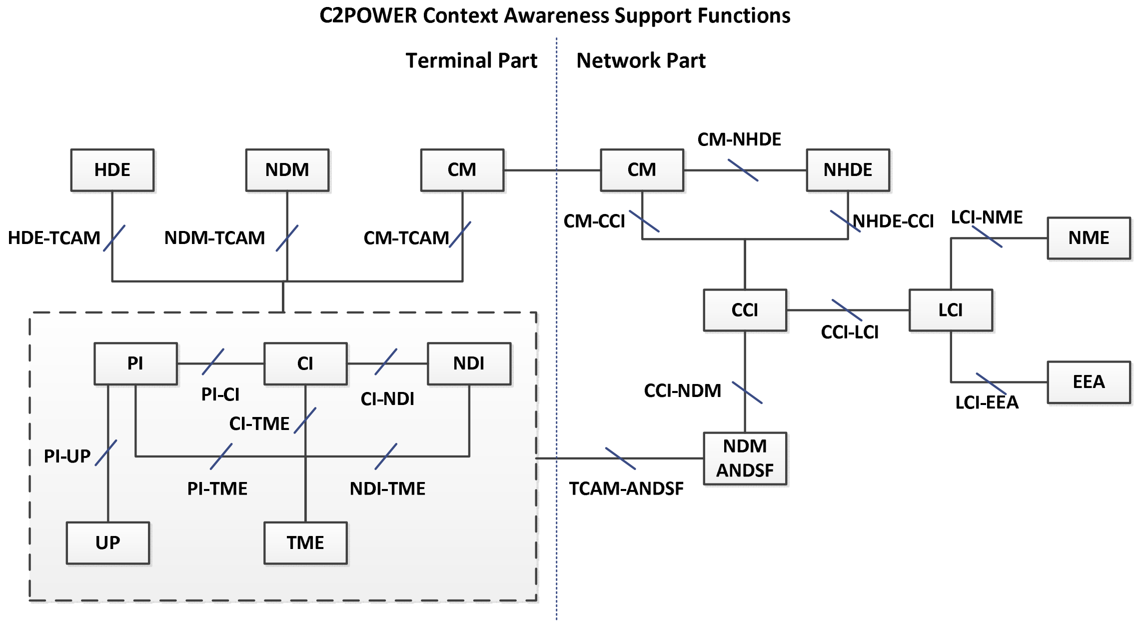

Figure 2.1. C2POWER Context Support Structure - System Interfaces [2]

The availability of information on the networking environment and the characteristics of the mobile terminals that is collected, processed and used by the various context awareness support functions, is of fundamental importance in the C2POWER architecture. This information provides the different modules with the necessary awareness of the surrounding environment, in network and terminal level, allowing them to efficiently adapt their operation towards the goal of energy consumption reduction.

Figure 2.2 depicts the four broad categories of network context information that are considered by the C2POWER context awareness architecture, and their further sub-divisions. The key categories include: i) the security levels that can be provided, ii) the policies, based on the user-operator and operator-operator agreements, iii) the coverage of the network and the co-existence of different networks and iv) the QoS, which describes the static and dynamic capabilities of the network.

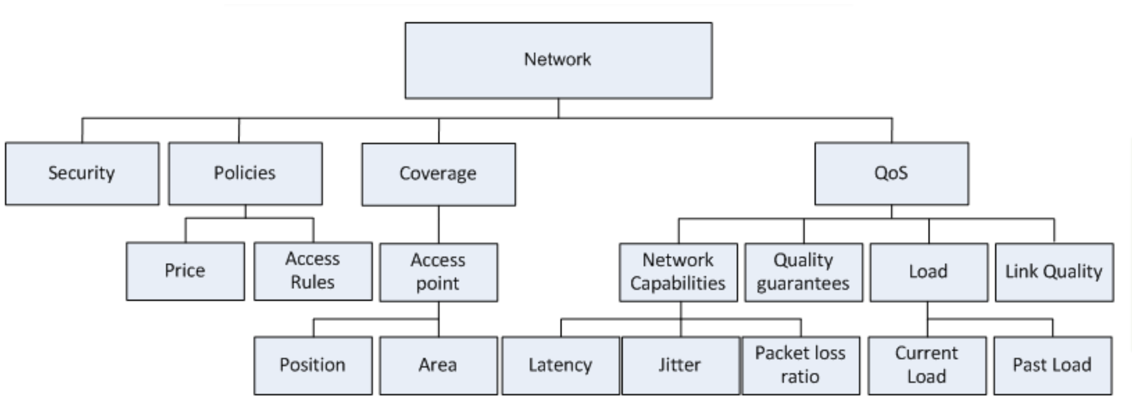

Figure 2.2. Network Context Information [1]

Similarly, Figure 2.3 represents the five main categories of mobile terminal context information that are considered by the C2POWER context awareness architecture. These include i) the description of the device capabilities, ii) the information on the current location and velocity of the mobile terminal, iii)the applications in use, iv) the energy information, which includes the current battery level, the energy history and the energy consumption, and v) the various parameters that constitute the user preference.

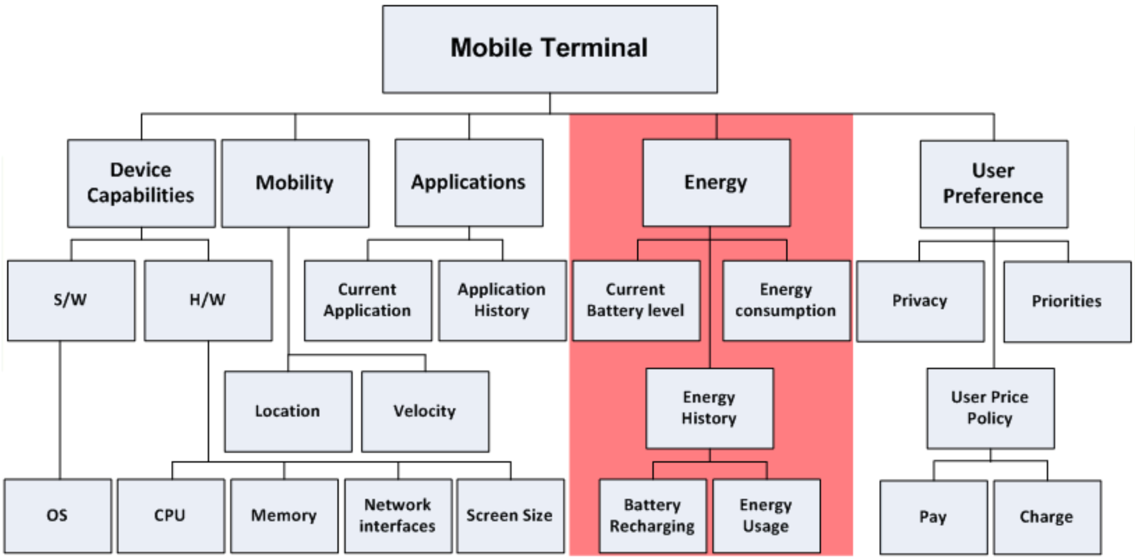

Figure 2.3. Mobile Terminal Context Information [1]

A detailed description of the types of network and mobile terminal context information taken into consideration by the C2POWER architecture can be found in [1].

3. Energy Efficient Candidate Network Discovery Mechanism

3.1 Motivation

In order to reduce its energy consumption and improve its provided QoS level, a user in a heterogeneous networking environment proactively scans for available access networks to obtain up-to-date knowledge of the network topology in his/her vicinity and performs vertical handovers to less power-consuming networks, when possible. Traditionally, in legacy networks, the procedure of network scanning is performed periodically, with a fixed pre-determined period, without considering any information on the conditions and requirements of the user or system. However, this often results in inefficient performance in terms of energy consumption due to the fact that context information, such as the availability of neighbouring networks, as well as the user's current position, speed and travelled distance since the last network scanning, are not taken into consideration. Therefore, mobile devices may be performing unnecessary energy-consuming network scanning, in situations when the user is moving very slowly or not moving at all and the surrounding topology does not change. Moreover, in the case of high user speed, the network scanning may not be performed frequently enough resulting in increased probability of misdetection of available less energy-consuming networks.

The recent literature on energy efficient network discovery mainly focuses on adaptively determining the most appropriate time for a user to perform a network scan, aiming to accurately detect available neighbouring networks without increasing the energy consumption [3]-[5]. More specifically, in [3], an energy efficient idle scanning strategy for local area networks is proposed. This method exploits the operating channels and Access Point (AP) density information provided by the Access Network Discovery and Selection Function (ANDSF) [6], defined by the 3rd Generation Partnership Program (3GPP). In [4], the authors propose a system that considers information on the user mobility and the AP density information to determine the Wireless Local Area Network (WLAN) [7] scanning period. However, the AP density information used is not explicitly provided by the network, but is calculated by the previously performed network scanning. In [5], the issue of vertical handover between integrated IEEE 802.16e [8] and WLAN networks is addressed. The proposed scheme allows a mobile user to decide whether to attempt AP discovery and how to set the 802.11 active scanning intervals. However, this scheme is designed to use standard IEEE 802.16e signalling and does not consider the possibility of vertical handover between IEEE 802.16e/WLAN and 3GPP networks.

To address the problem of network scanning period adaptation and improve the energy efficiency of the network scanning procedure, we propose a novel ANDSF-assisted network discovery algorithm that exploits information on the user location and on the location of available networks, in order to decide when to perform a network scanning. The aim of the proposed algorithm is to avoid unnecessary energy-consuming network scanning and misdetection of available networks that can be used as targets of handover. The performance of the system that employs the proposed algorithm is compared against a system that performs network scanning with a fixed period, without taking into consideration the user or the network context information.

3.2 System Model

The system model, as shown in Figure 3.1, consists of a large geographic area covered by a number of neighbouring Long Term Evolution (LTE) [9] cells (called eNodeB according to 3GPP), and a number of randomly distributed WLAN APs [7]. The User Equipments (UEs) who move randomly all over this area perform eNodeB selection and inter-eNodeB handovers based on the measurement of the received signal strength. Moreover, they regularly perform network scanning in order to detect the presence of a WLAN AP, to which they can connect. When an available WLAN AP is discovered by a UE, the UE will perform a vertical handover to the WLAN for better services and energy-saving transmission purposes. When the UE moves out of the coverage of the WLAN AP, the UE performs a WLAN-LTE handover. An ANDSF server is deployed at the Evolved Packet Core (EPC) acting as a database to record the network context, e.g., the WLAN AP location information. A UE is assumed to be able to estimate its current location using mature localization techniques such as Assisted Global Positioning System (AGPS) [10]. Moreover, a UE can estimate its movement information – i.e. its travelled distance – through its embedded accelerometer that is prevalent in current mobile phones. This operation consumes much less energy compared to GPS-like location estimation operations [11], and is often utilized by various phone applications.

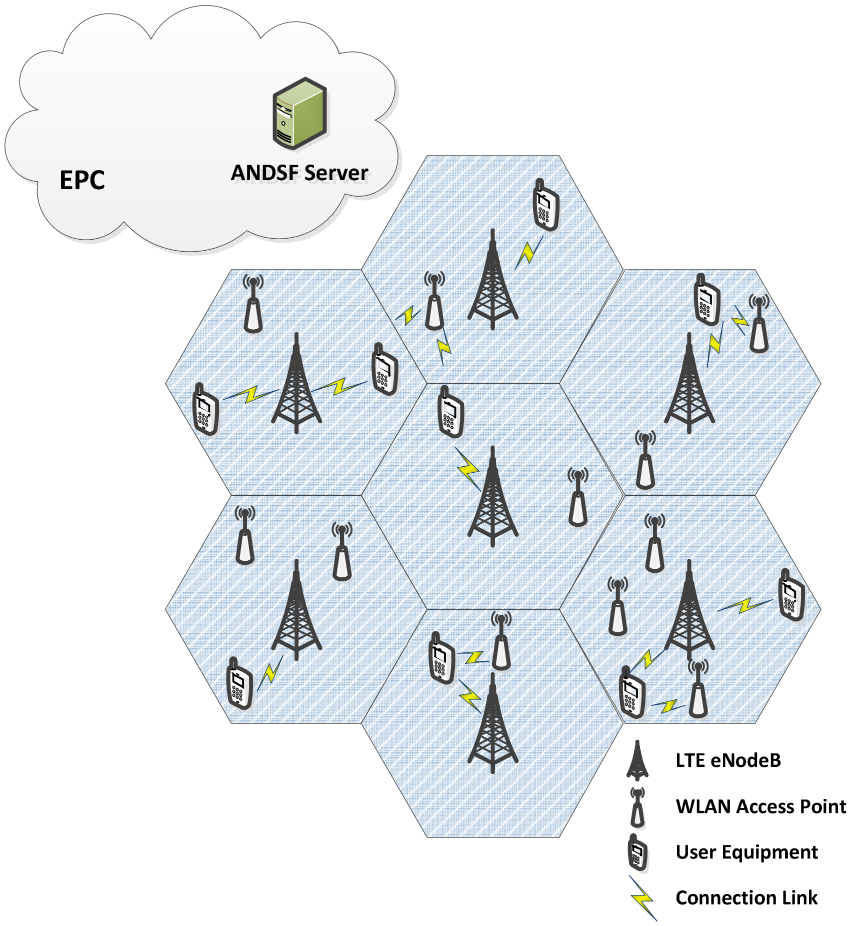

Figure 3.1. The system model

3.3 Algorithm Description

To improve the system performance in terms of energy efficiency and avoid unnecessary queries to the ANDSF and the subsequent network scanning, the proposed algorithm introduces a new UE context parameter that is taken into consideration in the decision for a network scanning initiation: the *query distance* d_q. The query distance is set as the distance between the UE and the closest WLAN AP discovered in the previous ANDSF query, as illustrated in Figure 3.2. According to the proposed algorithm, when the UE has travelled a distance $d$larger than d_q since the last ANDSF query, the UE estimates its current location and sends a new query with its location information to the ANDSF server. The ANDSF checks the network context and responds to the UE's query with a list of the available networks in the UE's coverage area, if any. The UE uses this information to perform the network scanning and possibly also performs a vertical handover. If there is no WLAN AP accessible by the UE at the current location, the ANDSF checks the WLAN AP map and sets a new query distance $d_q$to the UE. The UE then resets $d$and uses its embedded accelerometer to estimate its travelled distance. While more complex mobility prediction algorithms may be employed to further improve the performance, the algorithm proposed in this deliverable achieves a good balance in the trade-off between algorithm complexity and effectiveness, as shown in the next section, and is completely compliant with the 3GPP specifications.

The pseudocode of the proposed algorithm is shown in Figure 3.3.

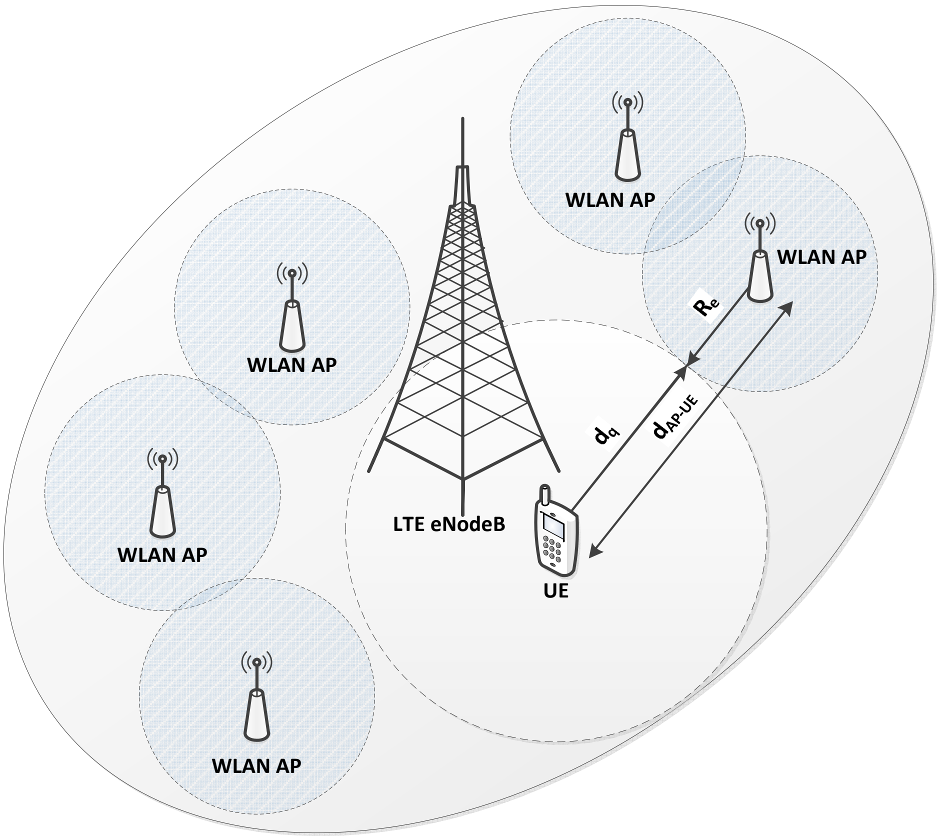

Figure 3.2. Illustration of the query distance d_q

ANDSF-Assisted Network Discovery Algorithm:

d ← Travelled distance since the last ANDSF query;
d_q ← Query distance;

IF $d > d_q$
    Query ANDSF;
    IF available WLANs within the UE coverage exist
        Perform network scanning;
        Perform vertical handover;
    ELSE
        d_q ← Distance to the closest AP estimated by the ANDSF, based on the UE location and APmap;
        d ← Null;
    END
ELSE

Figure 3.3. The pseudocode of the ANDSF-Assisted Network Discovery Algorithm

3.4 Performance Evaluation

To evaluate the performance of the proposed network discovery algorithm, a simulation model was constructed in C++. The performance of the proposed algorithm was compared against an algorithm that performs periodic network scanning with a fixed period of 1, 2, 3 and 6s, respectively, without taking into consideration the user or network context information. In the simulation scenario considered, the total energy consumption per user, the average network detection delay and the average network detection rate were measured with respect to the WLAN AP density, i.e., the number of available WLAN APs per km^2, and the user speed. The simulation parameters used are summarized in Table 3.1.

Figure 3.4 depicts the total energy consumption per user versus an increasing number of freely accessible APs per km^2, ranging from very low to increased AP density [15]. All users are travelling at 30 km/h speed. As it can be seen, the total energy consumption in the systems that perform periodic network scanning increases with the increase of the network scanning period. This is a result of the fact that the less frequently a network scanning is performed, the more opportunities to discover a WLAN network, that can serve as a target of handover and reduce the transmission energy consumption, may be missed. In this figure, it is also depicted that the system that employs the proposed ANDSF-assisted network discovery algorithm outperforms in terms of energy consumption all the systems that perform periodic scanning. This is a result of the fact that the use of context information for the network discovery allows the initiation of the network discovery procedure only when the user has travelled a distance which is long enough to increase the possibility of detecting an available network. Thus, on the one hand, the user avoids unnecessary energy consuming network scanning when there is no WLAN in the vicinity, while, on the other hand, the mobile device initiates network scanning frequently enough to allow quick discovery of available networks. The total energy consumed per user is relatively high for all schemes because, according to the simulation model, all the users are assumed to continuously transmit data during the entire simulation time.

Table 3.1. Simulation Model Parameters

Parameter	Value
Maximum LTE power in the uplink	250 mW
LTE cell radius	1 km
Path loss model in the LTE network	$PL = 128.1 + 37.6 \cdot \log d$, d in km [13]
LTE uplink power control	Open loop with fractional path-loss compensation
Maximum WLAN power in the uplink	100 mW
WLAN cell radius	50 m
Energy consumption per WLAN scan	11 mW [3]
Operational power	100 mW
Mobility model	Random Walk Model [14]
Number of LTE cells	7
Number of users	500
Simulation time	500 s

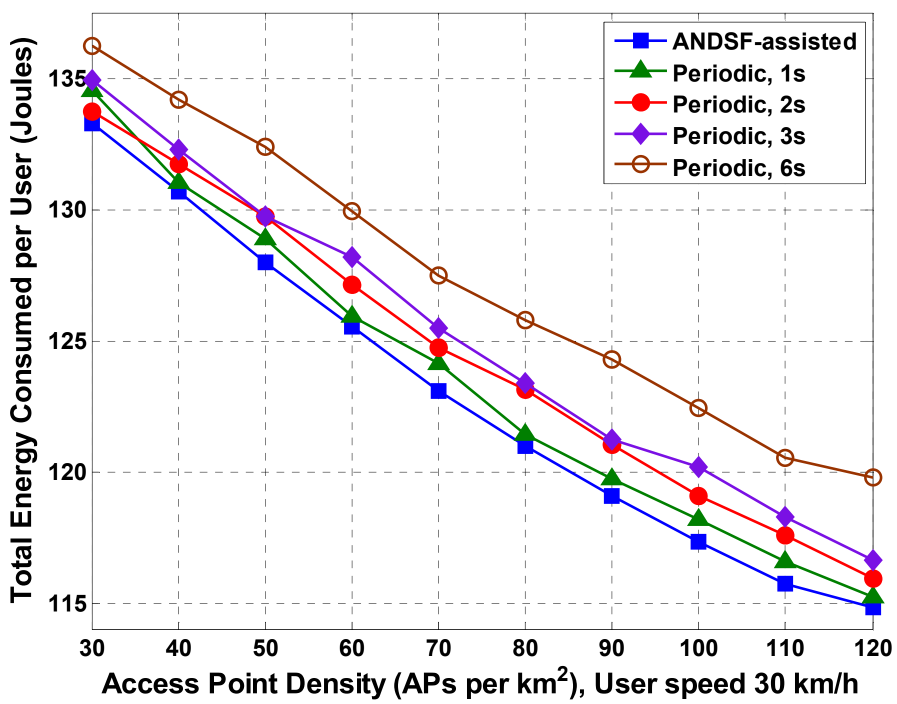

Figure 3.4. Total energy consumption per user versus the AP density

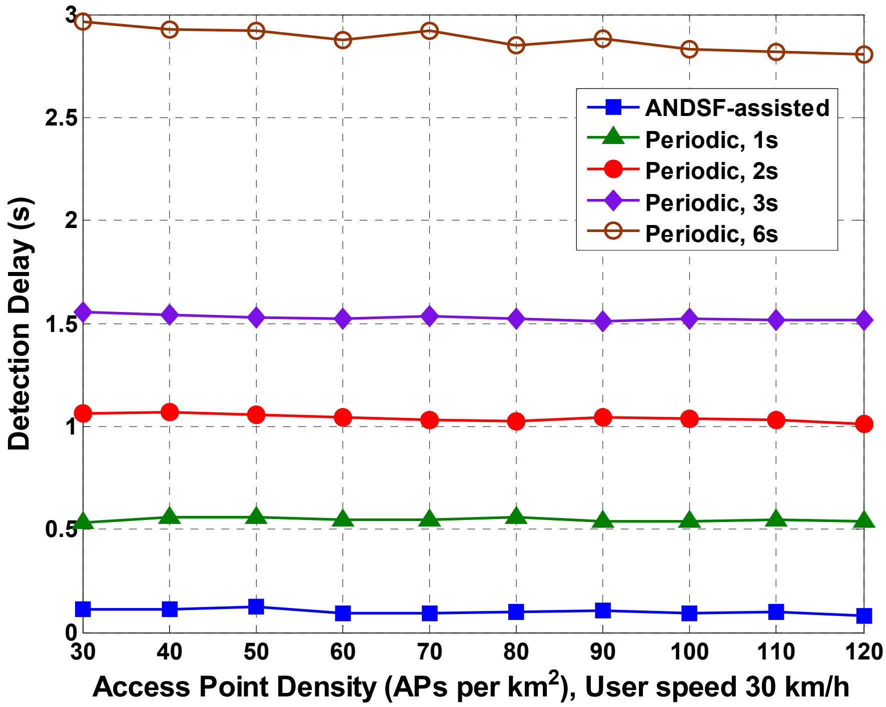

Figure 3.5. Average network detection delay per user versus the AP density

The average network detection delay, which is defined as the interval between the time a user first enters the coverage area of a WLAN and the time that the user discovers this network through network scanning, versus the AP density is depicted in Figure 3.5. As it can be seen, the system that employs the proposed network discovery algorithm takes advantage of the information on the location of the user and the available networks and achieves significant reduction in the network detection delay, compared to all the systems that perform network scanning periodically. Note that the fading channel is not considered here, and thus, the detection delay is evaluated based on the ideal coverage area of a WLAN. The detection delay in a real-world environment may be increased depending on the real WLAN coverage area.

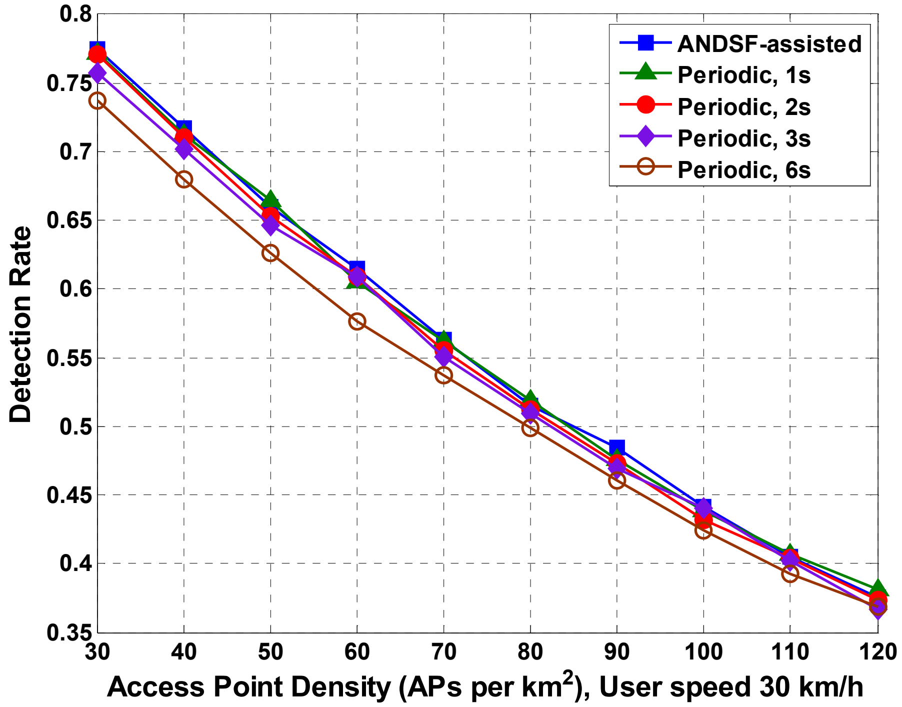

Figure 3.6. Average network detection rate per user versus the AP density

Figure 3.6 depicts the average network detection rate, defined as the ratio of the number of the networks a user has successfully detected over the number of networks, whose coverage area the user has entered. The system that employs the proposed network discovery algorithm has a similar, and sometimes slightly improved, detection rate compared to the systems that perform periodic scanning. Thus, it can be seen that the proposed algorithm can guarantee improvement in the total energy consumption and the network detection delay with no loss in the network detection rate.

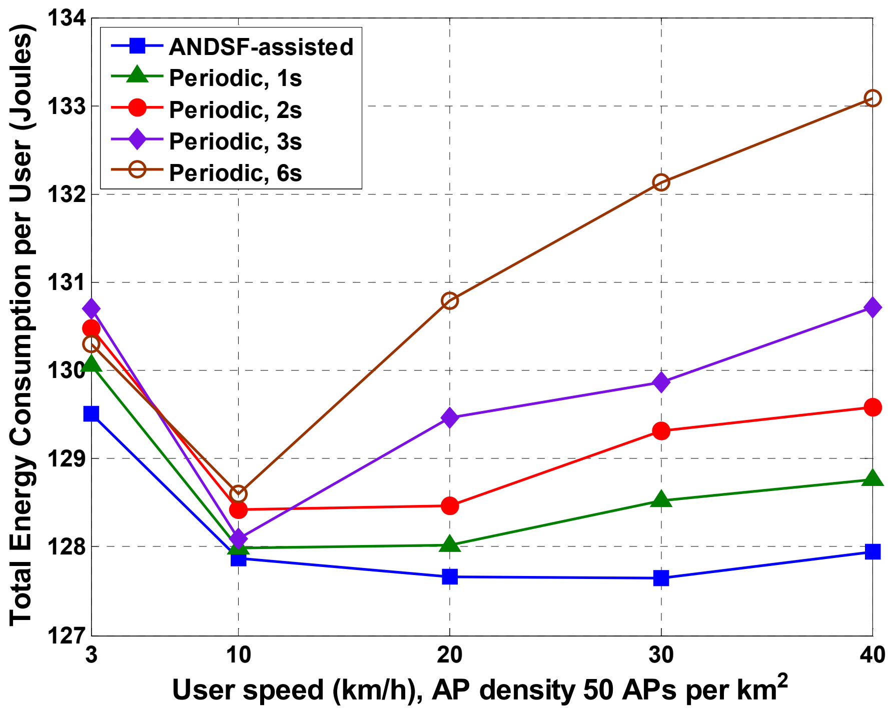

Figure 3.7. Total energy consumption per user versus the user speed

Figure 3.7 depicts the total energy consumption per user versus an increasing user speed that ranges from pedestrian to vehicular. The AP density is 50 APs/km^2. Similarly to the previous simulation scenario, the system that employs the proposed network discovery algorithm outperforms the systems that perform periodic scanning in terms of total energy consumption. This is a result of the fact that the use of both the user and the network context information for the network discovery allows the initiation of the network discovery procedure once it is considered necessary, based on the travelled distance by the user. It is interesting to see that the total energy consumptions of all the schemes will reduce first as the user speed increases, as mobility brings users increased possibility to access a WLAN. With the further increase of the user speed, the duration a user can stay in a WLAN is reduced, resulting in higher transmission energy consumption.

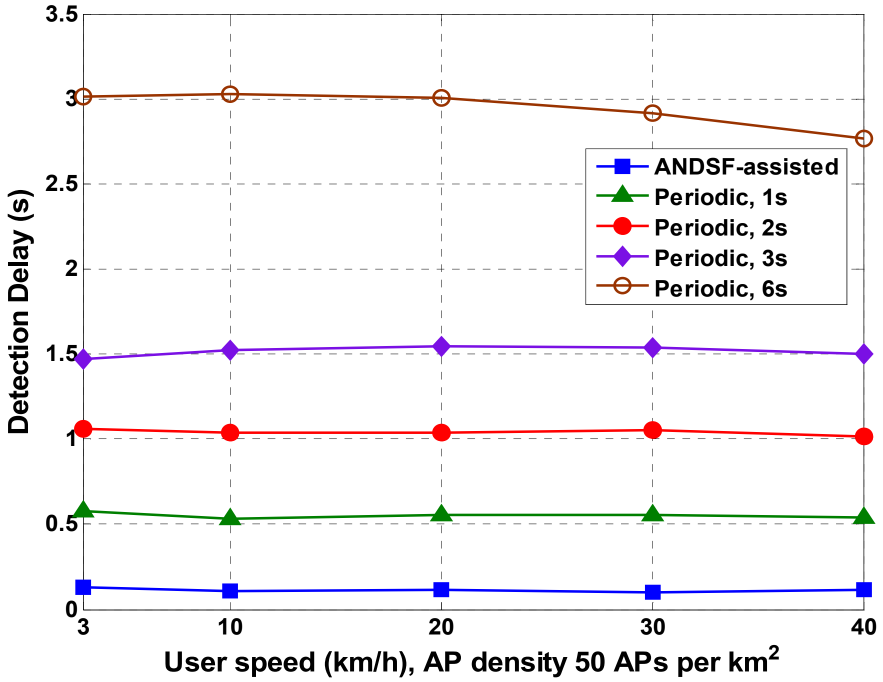

Figure 3.8. Average network detection delay per user versus the user speed

The average network detection delay with respect to the user speed is depicted in Figure 3.8. Similarly to the previous scenario, the proposed energy-efficient network detection algorithm achieves significant reduction in the network detection delay, even in the case of vehicular user speeds.

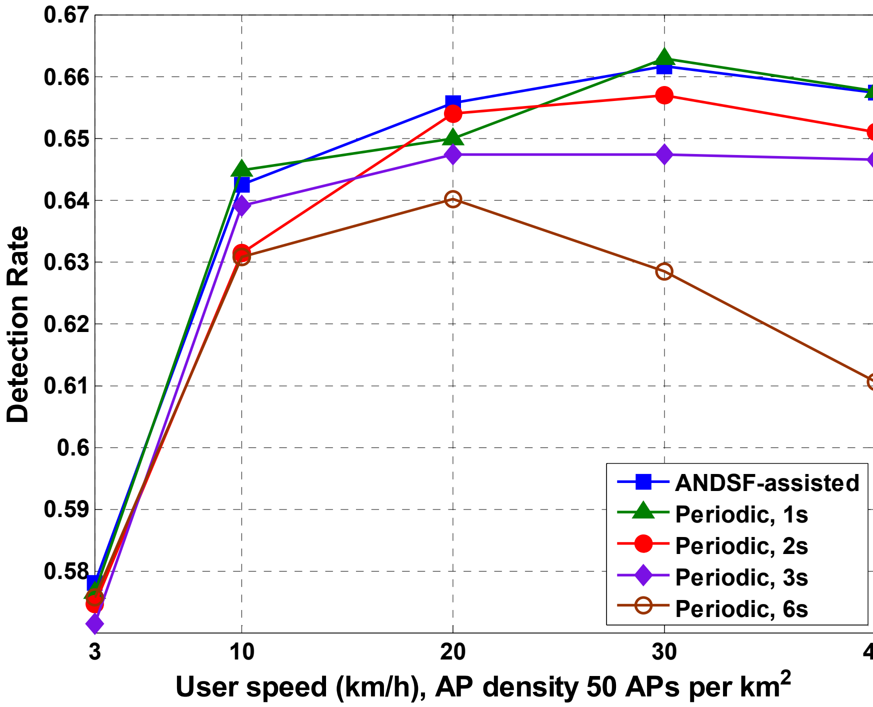

Figure 3.9. Average network detection rate per user versus the user speed

Finally, the average network detection rate with respect to the user speed is depicted in Figure 3.9. The system that employs the proposed network discovery algorithm has a slightly improved detection rate compared to the systems that perform periodic scanning.

4. Energy Efficient Node Discovery Mechanism

4.1 Motivation

Energy is a critical resource in battery-powered mobile devices. The problem of trimming down the energy consumption of mobile devices can be addressed by acting on different parts of the protocol stack, from physical to application layer. The node discovery process is the initial process that a node has to perform in order to start communicating with its neighbours. The knowledge on the available neighbours is important for Medium Access Control (MAC) protocols, as well as for the routing, cooperation initiation, mobility control, and topology control procedures. Node discovery, from an energy point of view, should be as fast as possible, as nodes spend a considerable amount of energy while gathering information about their neighbours. The energy consumption of every node during the discovery process depends on a number of activities, e.g., the amount of time spent in sensing beacons (Packets) or beacons transmitted to search for neighbour nodes in the range, the balanced active and sleep mode for the node discovery process, etc. The primary goal of an energy efficient node discovery process is to maximize the probability of node discovery in a specified time.

Most of the node discovery protocols and mechanisms are based on the conventional scanning which is expensive in terms of energy due to spending long periods in the “listening” state, and performing broadcast communication. To conserve energy, MAC protocols with proper sleep/wake duty cycles have been proposed for wireless networks, providing a balance in sleep and wake time of mobile terminals. Although suitable duty cycles contribute to energy conservation, keeping a node in sleep mode weighs down a network or a part of network. Furthermore, for a solitary node to discover another node or network even an efficient duty cycle cannot contribute effectively because the node does not know the suitable point in time or the exact location to turn on its interface to find a cooperative node. On the other hand, sometimes a node is in the vicinity of a cluster or a node, but lacks the knowledge about the cluster’s or node´s attributes to cooperate with, keeping in mind the wide range of frequency bands to scan. Taking into consideration the above mentioned problems, we define a scenario and propose a novel node discovery algorithm, to tackle both the node discovery and the cooperative cluster formation in an energy efficient manner.

4.2 Ultra-wideband Preliminaries

The Ultra-wideband (UWB) MAC channel time is divided into superframes. The total duration of the superframe is 65,000 µs and is composed of 256 Medium Access Slots (MASs) with duration of 256 µs each [19]. The superframe is further divided into two main parts, a Beacon Period (BP) and Data Transfer Period (DTP), as shown in Figure 4.1. In the BP, each user transmits its own beacon frame, which contains a number of Information Elements (IEs). These IEs have timing and control information of users to access the channel in a fully distributed manner and synchronization. The beacon frames represent the users’ information and a view of the network, which helps the incoming users to identify empty beacon slots, occupy them and transmit their beacons. The beacon frames are also used to reserve MASs in the DTP.

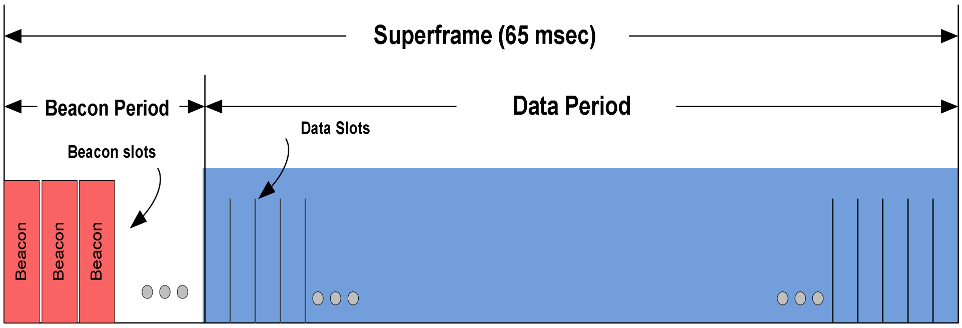

Figure 4.1. Superframe structure

The reservation of MASs in the DTP is reserved, modified or released via the Distributed Reservation Protocol (DRP) or accessed via Prioritized Contention Access (PCA). DRP is used to reserve the MASs for Time Division Multiple Access (TDMA), mostly for isochronous traffic or nodes that need guaranteed access to the medium. On the other hand, PCA provides differentiated channel access to the medium similar to IEEE 802.11e. When a node wants to reserve MASs for data transmission or reception, it negotiates with its neighbours via DRP IE and reserves a set of MASs. The DRP frame contains a number of IEs representing different pieces of information. The DRP contains the control IE, which shows owner, status of reservation, reason codes, reservation types and additional information on the reservation conflicts [19]. The device that wants to start the reservation process is called the owner and the device that receives the information for reservation is referred to as target. The type of reservation can be Hard, Soft, PCA, Private, or Alien BP. The Reservation status indicates the status of the DRP negotiation process, which shows whether a reservation is under negotiation, in conflict or established. The Reason Code is used by a reservation target to show whether a DRP reservation request was successful or not.

A DRP IE contains one or more DRP Allocation fields, which are encoded using a zone structure. The zone structure is split into 16 *zones* numbered from 0 to 15, starting from the BP which are further divided into *isozones*. In this two-dimensional structure of the WiMedia superframe, each column of the superframe matrix is called an allocation *zone,* as shown in Figure 4.2. In the reservation allocation IE, each node includes a Zone bitmap and a MAS bitmap. The Zone bitmap identifies the zones that contain reserved MASs and the MAS bitmap specifies which MASs in the zones identified by the Zone Bitmap field are part of the reservation. The reservation of MASs in the zones follows certain rules to ensure fairness; more details can be found in [19].

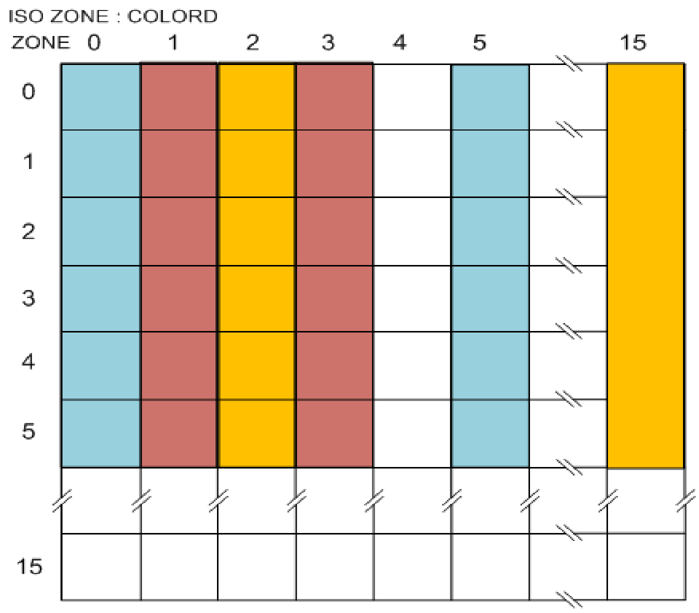

Figure 4.2. Superframe two dimensional view.

4.3 System Model

The system model is shown in Figure 4.3 and involves Mobile Terminals (MTs) that can communicate through a long range network, e.g. Worldwide Interoperability for Microwave Access (WiMAX), LTE, etc., and a short range network, e.g. UWB, Bluetooth, etc. We consider WiMAX and UWB, but the approach has general validity. The model covers cluster discovery and cooperation instantiation for a mobile terminal that is in search of a network or device. The cluster is based on the centralized approach, where the cluster-head is the centralized coordinating entity. Our approach uses the context information about the cluster, e.g., location of cluster, battery levels of member devices, and willingness to cooperate. Furthermore, inside the cluster we defined two groups of member devices: i) a group consisting of devices that are considering switching to the hibernation state to save their energy, since once a device is in hibernation mode it will not be considered as candidate for cooperation, and ii) the second group consisting of the devices in active mode and the devices that could be interested in cooperating with the external devices, depending on their battery levels and willingness to cooperate. As shown in Figure 4.3, a cluster connected with the Base Station (BS), and the clusterhead of each cluster (in case multiple clusters exist) sends its cluster information to the BS so that, when a device looks for short range connectivity, the BS can provide information about the nearby cooperative clusters. The information is then utilized by the mobile terminal to connect to the devices in an energy efficient way.

For the exchange of the Cx-list inside the cluster and with the BS we consider the three following cases:

Case 1: In the first case, the Cx-list is extracted periodically only from the clusterhead that does not update the information except, when some serious topology change is triggered.

Case 2: In the second case, the clusterhead collects the Cx-list and periodically or on demand sends it to the BS as well as to the other members.

Case 3: In the third case, all member devices in the cluster pack the information into a Cx-list that is sent to the clusterhead and also to the member devices in an ad-hoc fashion. In this case, the cost of sending the Cx-list is for all the devices. A Cx-list exchanged between all the devices will allow them to know the characteristics of each other and also the external devices that want to be part of this cluster.

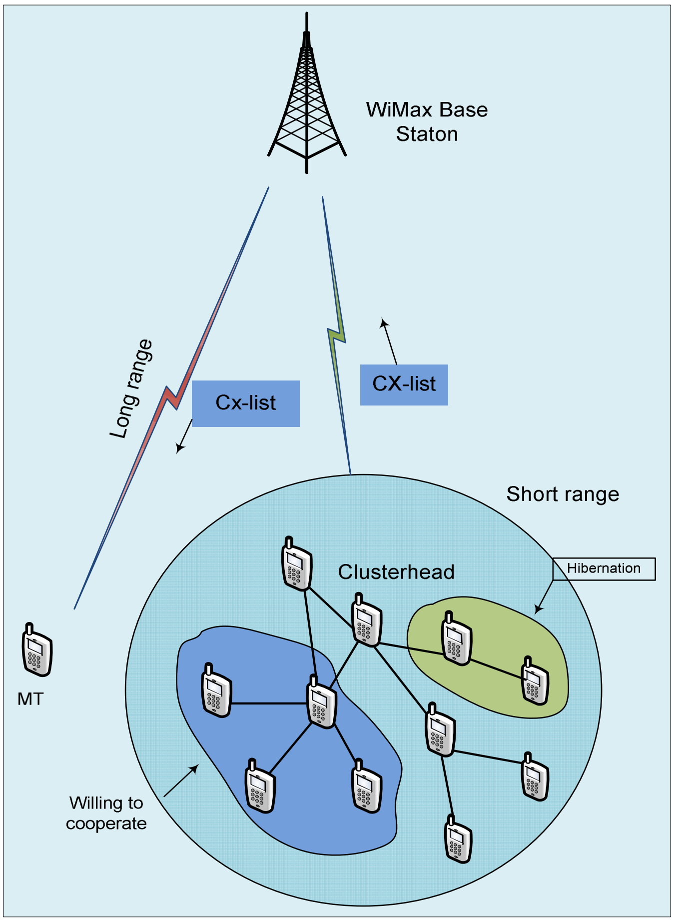

Figure 4.3. System Model for Node discovery

4.4 Algorithm Description

Both the discovering MT and the clusterhead are connected to the WiMAX BS. Once the battery level (BL) of the MT reaches a threshold battery level (BLth), it triggers the BS for a Cx-list of nearby co-located short range networks. The BS can send the Cx-list to the MT, without request/triggering from the MT, if the BS knows of a cooperative cluster in the vicinity of the MT. The Cx-list is the list of context information that the clusterhead sends to the BS for future connectivity with nearby devices. The Cx-list contains useful information, e.g., members of the cluster willing to communicate, Battery levels, current transmission power, Cluster ID (in case of multiple clusters), etc. The Cx-list constructed by the clusterhead floats via the WiMAX network to the discovering MT device. The Cx-list facilitates the searching MT to know important characteristics of the clusterhead or its members, e.g. battery level, channel information, etc. The context information is used for three different goals:

- Creating a list of possible co-located MTs that are willing to cooperate

- Facilitating the communication. The exchanging of reserved channels, location etc.. is used to direct the scanning, without having to check the presence of MTs on different channels.
- Setting up a rendezvous with other MTs. The timing information can be used to know in advance when the next superframe will start. The timing information will be used to shorten the active mode (transmission and reception) phase, starting just a little before the probable start of the superframe, to take into account the delay in receiving this synchronization information from the long-range WiMAX.

The flowchart of the proposed node discovery algorithm is shown in Figure 4.4.

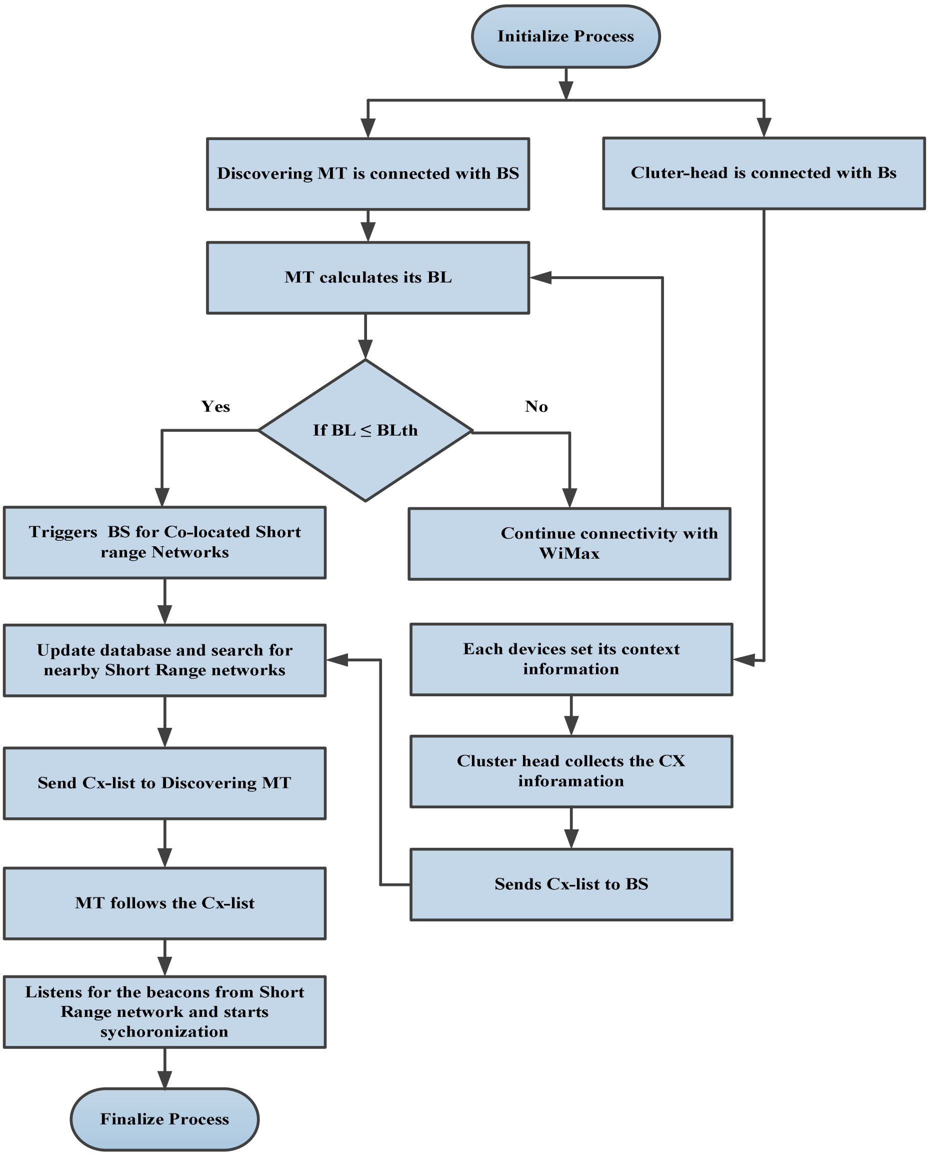

Figure 4.4. Flowchart of the proposed node discovery algorithm.

4.5 Mathematical Model for the proposed algorithm

Let E_{x1} be the energy consumption of User *X* while scanning, during the discovery process. We divide the scanning process into two modes, Active and Sleep, as shown in Figure 4.5b. The device consumes E_{xA} energy during the active mode and E_{xS} energy during the sleep mode. Each duty cycle consists of a number of switches during the scanning process during which the MT scans for the available nearby nodes, represented by *N*.

In the absence of context information, the MT turns on its short range interfaces and starts scanning, following a normal duty cycle. Based on the above definitions, the energy consumption without context information is calculated as follows:

$$E_{x1} = \frac{N}{2}\left(E_{xA} + E_{xS}\right). \tag{3.1}$$

N is the frequency of switching and depends on the user speed V, as shown in Figure 4.5a. A largevalue of N is recorded when the speed is low because the searching node will get excessive switching time.

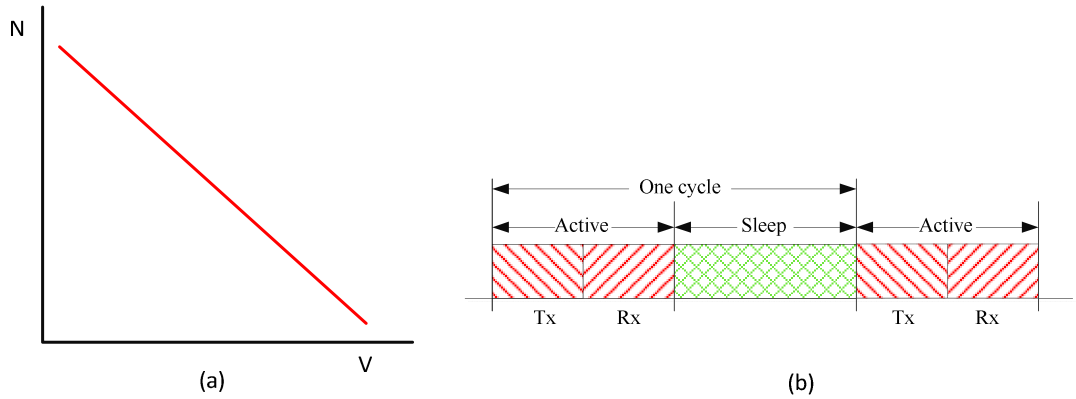

Figure 4.5. (a) Value of *N* according to user speed (b) MAC duty cycle.

Let us consider E_{x2} as the energy consumption while using the context information. Thus,

$$E_{x2} = N\left(E_{xS}\right). \tag{3.2}$$

From Equations (3.1) and (3.2) we can calculate the energy saving Es, as follows

$$\begin{aligned} Es &= \frac{N}{2}\left(E_{xA} + E_{xS}\right) - N\left(E_{xS}\right) \\ &= \frac{N}{2}E_{xA} + \frac{N}{2}E_{xS} - N.E_{xS} \\ &= \frac{1}{2}\left[N\,E_{xA} - N\,E_{xS}\right] \\ &= \frac{N}{2}\left[E_{xA} - E_{xS}\right] \end{aligned} \tag{3.3}$$

Let Gs be the energy gained. Then:

$$Gs = (\frac{E\mathrm{s}}{E_{\mathrm{x1}}}) \quad (3.4)$$

From Equations (3.1) and (3.3) we define the energy gain as:

$$\begin{aligned} Gs &= \frac{\frac{N}{2}\left(E_{\mathrm{xA}} - E_{\mathrm{xS}}\right)}{\frac{N}{2}\left(E_{\mathrm{xA}} + E_{\mathrm{xS}}\right)} \\ &= \frac{\left(E_{\mathrm{xA}} - E_{\mathrm{xS}}\right)}{\left(E_{\mathrm{xA}} + E_{\mathrm{xS}}\right)} \end{aligned} \quad (3.5)$$

When a node has to initiate a communication, it searches for the available channels. During each attempt and back-off mode, the node consumes energy. The total energy consumed depends on E_T, E_R and E_{B-off} (Back-off energy). So let E_{Total} is the total energy consumed during the node discovery process then

$$E_{Total} = E_T + E_R + E_{B-off} \quad (3.6)$$

In our proposed mechanism we have reserved the channel for the discovery node and we assume that all the member devices of the network know this information. The energy consumption increases as the node spends more time in the backoff mode and reattempts periodically, as shown in Figure 4.6 and described by the following equation:

$$C_{Attempts} * E_{Attempt} = E_{Total} \quad (3.7)$$

The probability comparison of the node discovery that follows the context based approach and the conventional discovery approach is shown in Figure 4.6. The conventional approach consumes more energy due to the more attempts for the discovery, as compared to the context based discovery.

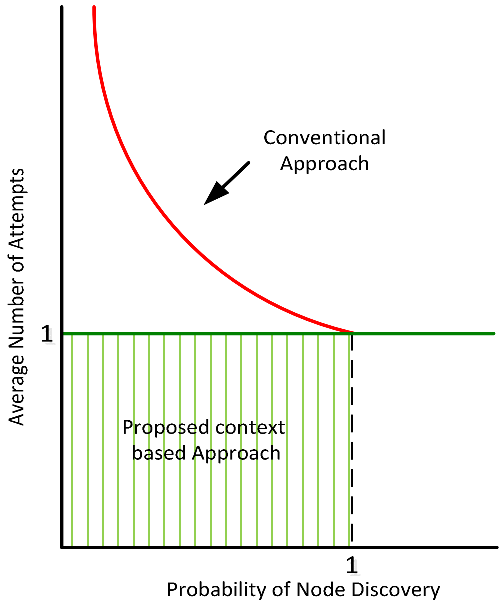

Figure 4.6. Probability comparison of node discovery by Context based approach and conventional discovery approach.

4.6 Performance Evaluation

The proposed node discovery mechanism is simulated using OMNeT++4.0 [16], an open source simulator. We installed the Numbat WiMAX/Mobile IPv6 framework for OMNeT++[17] for long range simulation results. For the energy calculation, we used the Energy Framework of OMNeT++, which is a collection of modules that allows flexible and extensible modelling of battery consumption of wireless devices[18]. From the existing modules available in OMNeT++, we used the *SimpleBattery* module, which is a simple linear battery model that provides a common interface to all battery using devices. The battery status of each device is recorded asa time series with the events and results being published in vectors. The resolution depends on the battery's *publishDelta* value set in the main program. We set its value to 0.1, which means that after each 0.1 s the battery data is published to a file which shows the energy consumption in different events.

The simulation consists of a cluster of 10 nodes and a searching node. The discovering node moves with different motilities and tries to find the cluster by using both context based discovery and conventional scanning. The simulation setup is shown in

Table 4.1.

Table 4.1. Simulation Setup

Parameters	Value
Simulation Area	500 m x 500 m
Short range Technology	UWB
Long range Technology	WiMAX
Battery module	Omnet++ 4.0 Simple battery
Nodes in the cluster	10
Mobility Models	Constant Speed Linear Mobility Rectangular (Defined areas)
Node speed	2m/s
Node update interval	1s
Number of nodes	5
Cx-list size	32,64,128,256,512 bytes
Initial node Battery	7mAh
Voltage	3.3 V
Maximum transmission power (UWB)	1 Mw
Backoff time	0.0003 s
SIFS	0.00019 s
Time from RX toTX mode	0.00018 s
Time from RX to Sleep mode	0.000031 s
TimeTX toRX mode	0.00012 s
TimeTX toSleep mode	0.000032 s
TimeSleep to RX mode	0.000103 s
TimeSleep toTX mode	0.000203 s

In the proposed scenario, if MT-A does not find any cooperative node or cluster and continues its connection with the long range technology, its battery will be drained out very swiftly. Figure 4.7 and Figure 4.8 represent the need for short range technologies for energy saving and also validate our energy saving mechanism by using WiMAX as facilitating technology to short range UWB in the node discovery process. We have generated a series of traffic with different data payload sizes and checked their energy consumption in the UWB and WiMAX networks. Figure 4.7 shows that the long range communication is expensive in terms of energy consumption. The energy consumption of the MT also depends on the data rates, payload size and the distance between the communicating devices. Since UWB offers high data rates, the transmission time is lower compared to WiMAX and the result in Figure 4.8 shows that the transmission time is proportional to the data payload size.

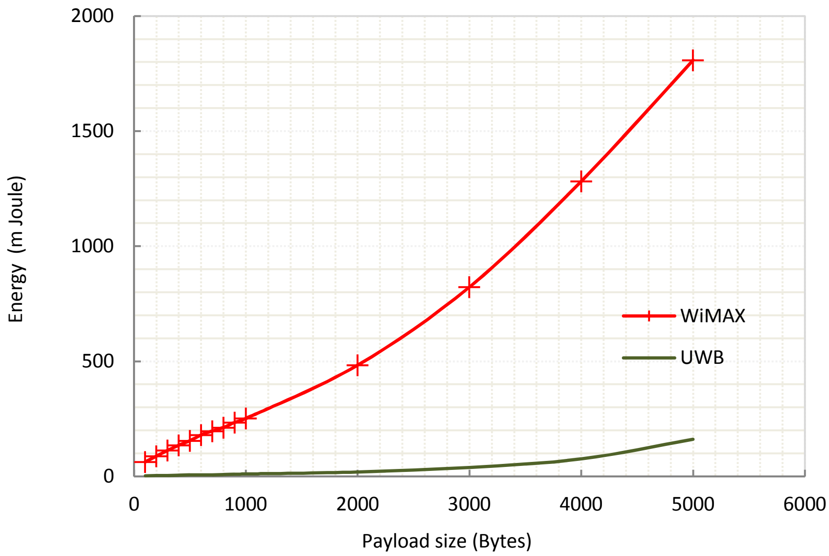

Figure 4.7. Energy consumption of different payload sizes over UWB and WiMAX

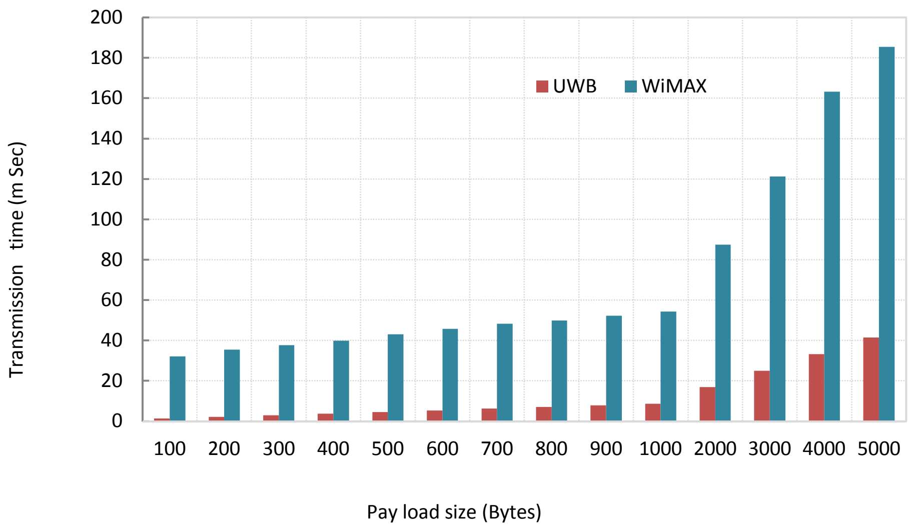

Figure 4.8. Transmission time UWB and WiMAX with data payload size

Turning on the short range interface at the exact location once the discovery node is in the coverage area of the short range cooperative cluster is very critical, as the node has to consider the communication delay of the context list. We performed a series of simulations to check the transmission time when the beacon packets success rate is zero and when its success rate is almost 100 % during the discovery process. We can see in Figure 4.9 that the beacon packets success rate is 0 when the node is not in the coverage area, but once it starts to touch the boundaries of the cluster the success rate goes higher and reaches to its peak value in 5 seconds. For optimal connectivity, the discovering node has to switch on its short range interface and receive the fresh context list in 5 s. The coverage area of the UWB in this case is exactly 10 m.

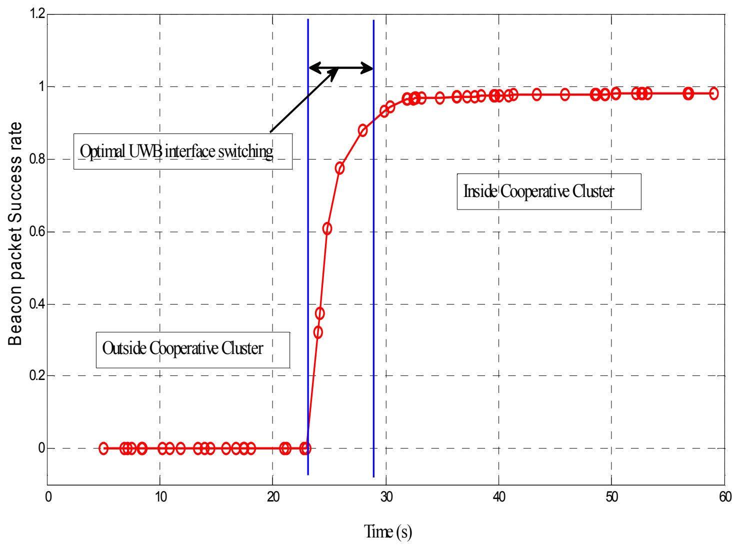

Figure 4.9. Beacon Packet success rate.

As described in the previous sections, to assist the searching node to discover a cooperative node or a cluster, the clusterhead of each cluster gathers the information into a context list about all member nodes and sends it to the WiMAX BS. The context information floats over via the WiMAX connection and is received by the device. Figure 4.10 shows the energy consumption of a context list with different sizes over UWB and WiMAX. The size of the Cx-list ranges from 32 bytes to 512 bytes in order to check the energy consumption variation and to validate our mechanism. The results show that the energy consumption for different sizes of the Cx-list of WiMAX is higher than UWB, but negligible compared to the overall energy gain of the mechanism.

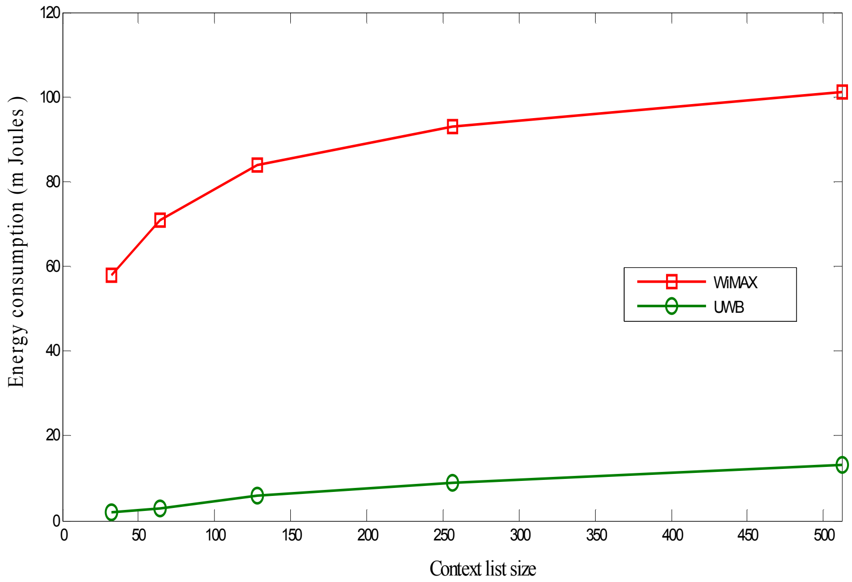

Figure 4.10. Energy consumption comparisons of Cx-list via WiMAX and UWB

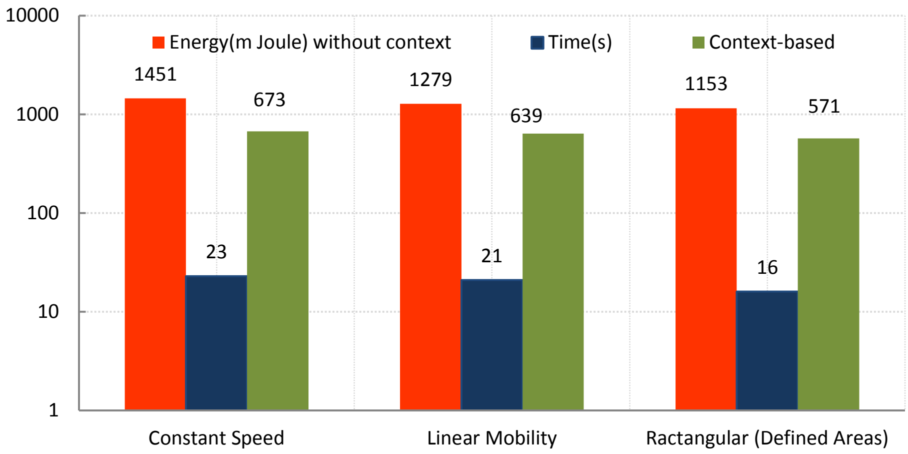

Figure 4.11. Energy cost of node discovery with and without context information, and time to discover first node with and without context with different mobility models

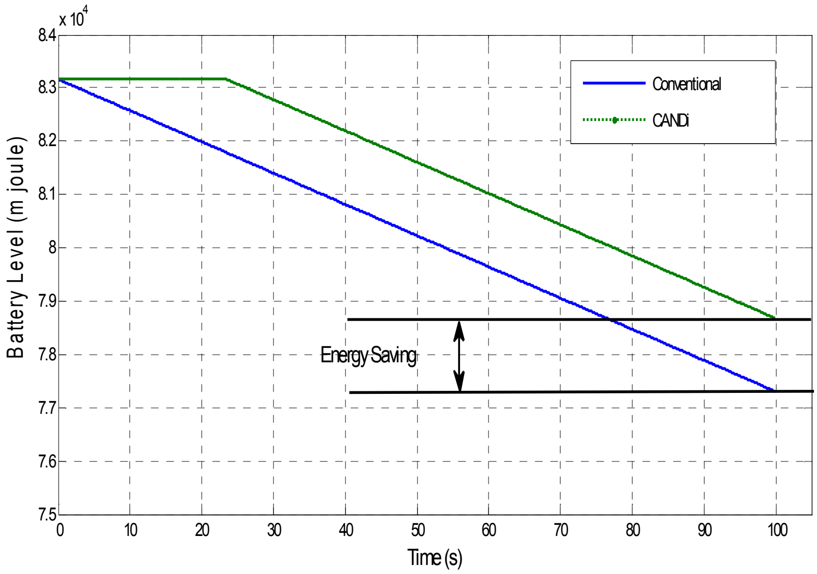

Figure 4.12. Energy consumption of scanning process

The time to discover the cluster varies with the different mobility models. This is the time considered in the context based discovery to keep the short range interface off and save energy. The energy consumption of the node discovery with different mobility models is shown in Figure 4.11. We have used Constant speed, Linear and Rectangular (defined areas) mobility models. In all simulations, the node´s power has been kept constant to 1mW and the speed to 2 m/s. Figure 4.12 shows the energy consumption of the node when it scans blindly without any context information to find a cooperative cluster and with context based scanning. A number of experiments have been performed to record the average time when the node is in the range of short range technology. Despite the reasonable duty cycle of sleep and active mode of the MAC, the energy consumption of the node in the discovery process is high. Figure 4.12 shows that the context based discovery process saves a considerable amount of energy.

The analytical and simulation results of the proposed context based algorithm are shown in Figure 4.13. The fraction of discovery nodes is high in the case of the analytical results, as we are not considering the context list delay over WiMAX compared to the simulation results. In the simulation results, we consider the re-transmission of lost beacon packets, the node back-off modes and the delays of the context list from WiMAX as a result the fraction of the discovered nodes is lower compared to the analytical case. In the conventional discovery case, the channel is not reserved for the incoming node to the system and in case the beacon period is saturated the discovery node has to wait for a considerable amount of time and to re-attempt in order to find a free channel. In the proposed context based discovery, we reserve the channels and the MASs for the incoming node, which provides an ease to discovery process and the member nodes of the cluster are aware of incoming node to the system which helps in synchronization. Due to context facilitation, the proposed algorithm discovers more nodes with the same amount of available frames compared to the conventional discovery process as depicted in Figure 4.14.

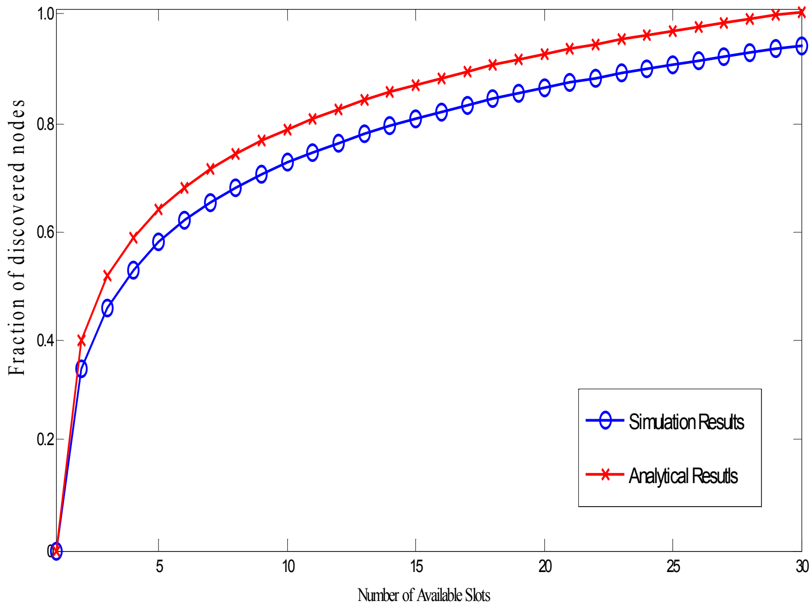

Figure 4.13. Analytical and simulation results comparison of Context based discovery

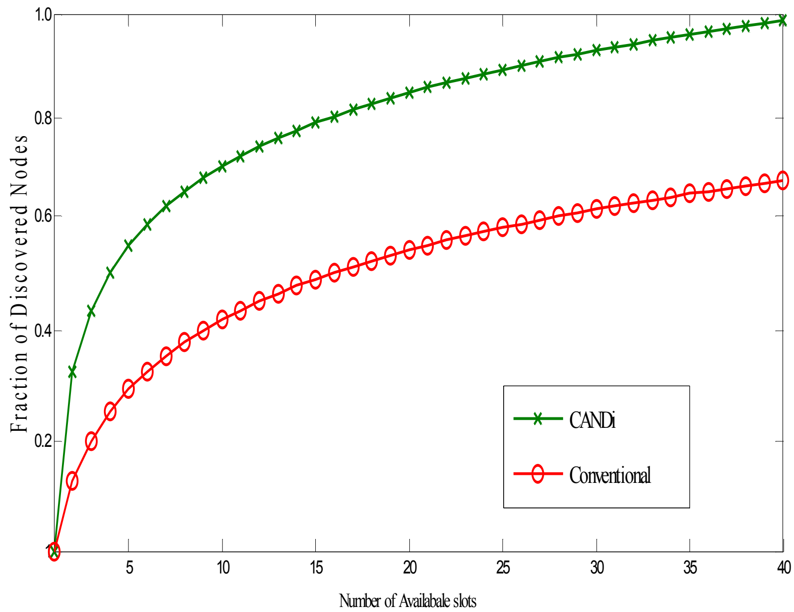

Figure 4.14. Simulation results comparison of context based discovery and Conventional Node discovery

With the conventional scanning process, the MAC layer periodically switches between the sleep and active modes. By active mode we mean both the sending and listening states, while the sleep mode considers both the idle and sleep modes. In the absence of prior knowledge of nearby nodes or clusters, the node scanning process is quite expensive in terms of energy. On the other hand, C2POWER nodes use context based scanning to switch to the active state and start communicating at the time they reach the coverage area of the cluster. As shown in Figure 4.15 terminals save 50% energy in the short range discovery process compared to the normal discovery process.

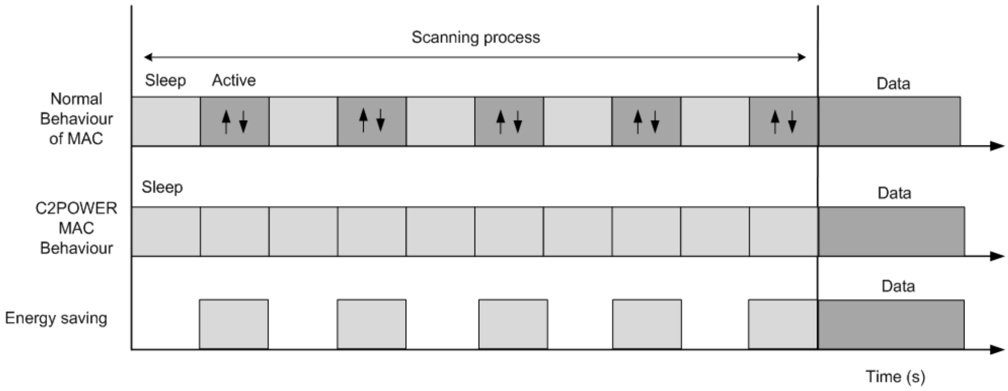

Figure 4.15. Energy consumption comparison of scanning process of C2POWER and conventional Scanning process.

5. Conclusion

This deliverable is the final version of deliverable D3.2 and provides detailed descriptions of the context-aware energy efficient network and node discovery mechanisms designed and implemented in Workpackage 3 of the C2POWER project. Moreover, the performance of the proposed mechanisms was evaluated through simulations that compared their performance with legacy systems that do not consider any context information during network and node discovery, respectively.

The deliverable introduces the context aware architecture proposed and designed within the C2POWER project. It highlights the role of the context information of the network and node in reducing the energy consumption of mobile device, specifically during the scanning procedure in search of networks or neighbouring nodes existing in the vicinity. The deliverable briefly sheds light on the various categories of network and user context information.

In addition, the deliverable presents in details the energy efficient solutions of C2POWER to the issue of network and node discovery mechanisms. In general, network or node discovery processes are hectic and consume excessive amount of energy, since they usually includes continuous scanning of the available frequency bands, looking for broadcasting network or node in the vicinity. C2POWER advances the state-of-the-art by using the context information to reduce the scanning process and direct the nodes to when and where to scan for nodes or networks.

The deliverable introduces two mechanisms, one for network discovery and another for node discovery. The two algorithms are described in detail and their performance is assessed through extensive simulations. The network discovery takes advantage of the information available in the ANDSF, defined within the 3GPP project, while the node discovery algorithm depends on context list containing information about existing clusters and their members, sent by the cluster heads of such clusters. Both algorithms take advantage of context information available in the network and node to instruct mobile devices about when and where to switch on their interfaces and start scanning.

The simulation results show the energy savings achieved by the discovery algorithms compared to traditional discovery algorithms using continuous or periodic scanning. The results also show that the proposed algorithms decrease the misdetection rate, as well as lower the detection delay.

C2POWER has shown that discovery algorithms are usually expensive in terms of energy consumption, but using context information about nodes and networks, significant energy savings can be achieved.

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