

Zigbee Based Collaborative AP Discovery

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Abstract— With the fast development of mobile devices and wireless technology, more and more mobile devices are equipped with multiple network interfaces. Particularly, due to its high throughput and low cost, Wi-Fi is becoming one of the most popular interfaces. However, the high power consumption hinders its daily use in mobile devices to some extent. To tackle this problem, we present a Zigbee based Collaborative AP Discovery scheme (ZCAD) in this paper. ZCAD empowers mobile devices to share the ambient AP (Access Point) information (e.g., SSID, signal strength) via Zigbee interfaces, which enables mobile devices to directly associate with the available APs without first scanning them. Extensive experimental results demonstrate that ZCAD can significantly decrease the number of scanning for AP discovery and therefore effectively reduce the power consumption of Wi-Fi communications.

Keywords— Wi-Fi; Zigbee; energy efficiency; AP discovery; mobile devices

I. INTRODUCTION

Currently, most of mobile devices are equipped with multiple network interfaces, such as Wi-Fi, Bluetooth and Zigbee. Among these interfaces, Wi-Fi, due to its high throughput, low cost [1], is becoming more and more prevalent. However, Wi-Fi interfaces consume much energy during scanning for available APs (Access Point), which hinders its further use in mobile devices to some degree.

Much work has been done to address this problem by leveraging the multiple interfaces to reduce the total power consumption. For example, Footprint [2] uses cell tower information to infer the location of mobile devices to avoid unnecessary Wi-Fi scanning. Blue-Fi [1] can predict the availability of Wi-Fi by using Bluetooth contact-patterns and cell-tower information. Generally speaking, most of the work focuses on leveraging the cellular and Bluetooth information to infer or predict the available APs' information. However, because of its inaccuracy, cell tower information is impractical for predicting Wi-Fi AP in many cases; Bluetooth also has two problems: short range (about 10m), and time-consuming device discovery process (about tens of seconds), which greatly limit its uses. Based on the above observations, we make an innovation that we propose a Zigbee based Collaborative AP Discovery scheme (ZCAD) by leveraging Zigbee radio in this paper. The Zigbee interface uses less power consumption than the Bluetooth interface and the

cellular interface while its response delay is much smaller — it just takes 15ms for Zigbee to transfer from sleep state to working state. Furthermore, its communication range (10 - 100m) is longer than Bluetooth.

ZCAD makes full use of Zigbee radio's low power consumption characteristic and the collaboration between mobile devices to reduce the number of Wi-Fi scanning for AP discovery. The process of ZCAD is as follows: a few mobile devices first scan the available APs using Wi-Fi interfaces and then share these APs' information (e.g., SSID, signal strength, connecting time) via Zigbee interfaces to other Wi-Fi devices in the same area. Through this collaboration, mobile devices can easily obtain the information of nearby APs, and directly associate with these APs without scanning.

A critical point of ZCAD is how to guarantee the effectiveness and validation of AP information. As described above, the AP information plays a core role in our scheme, the effectiveness and validation of AP information is critical to the performance of ZCAD. We proposed an AP information updating algorithm to address the issue. Moreover, we developed an AP information selectively broadcasting algorithm for the devices to efficiently share AP information, and an AP selecting algorithm for the mobile devices to select an optimal AP. The three algorithms above are the main parts of our collaborative AP discovery scheme, which will be detailed discussed in section 3.

What should be noted is that ZCAD is only applicable to Wi-Fi always-on mode [2], in which Wi-Fi interfaces are always turned on. An always-on Wi-Fi connection has many desirable features for mobile users, for example, it enables quick discovery of APs and automatic AP switching without user attention. And it can provide much better performance for the application that needs a long-term network connection than that in on-demand mode.

For most of the mobile device are not equipped with Zigbee interfaces currently, we adopt the *uSD* Card (shown in Figure 1) [3][4] in this paper, which is developed by Nokia Research Centre (Beijing). A *uSD* Card looks like a mini SD card in shape that can communicate with other devices via Zigbee radio, and can be easily integrated into mobile devices.

The rest of the paper is organized as follows. Section 2 presents the related work. Section 3 provides a detailed description of our Zigbee based Collaborative AP Discovery Scheme. Experiment and analysis are presented in section 4. Section 5 provides some concluding remarks.

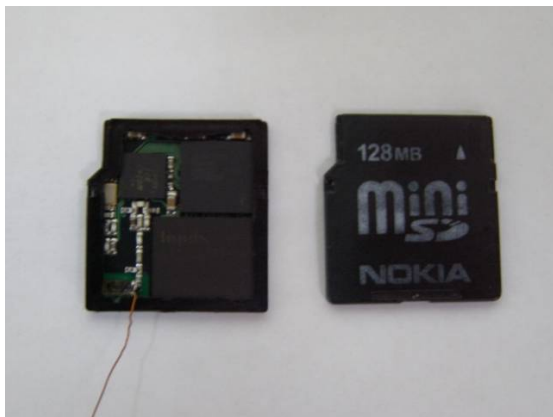


Figure 1. uSD Card

II. RELATED WORK

A number of solutions have been investigated to improve energy efficiency of Wi-Fi interfaces. Each solution focuses on a different aspect, ranging from Wi-Fi protocol optimizations, across-layer designs to multiple network interface collaboration to improve the Wi-Fi energy efficiency.

In 2002, Krashinsky et al proposed an optimal solution to the problem of minimizing energy consumption – a BSD (Bounded Slowdown) protocol to optimize Wi-Fi MAC layer by imposing a bounded delay on Power Save Mode (PSM) guaranteeing that a connection's RTT (Round Trip Time) does not increase by more than a factor p over its base RTT, where p is a protocol parameter that exposes the trade-off between minimizing energy and reducing latency [5].

The ideas of leveraging multiple network interfaces to improve the systems' energy efficiency are proposed in [1][2][6][7]. In 2002, Shih E. et al [6] proposed the "Wake on Wireless" scheme, which investigated the use of a second lower-power radio to wake up the primary radio in order to save power, but it brings high latency. Coolspots [7] explored the policies that enable a system to switch among multiple interfaces, each with different radio characteristics and ranges, to save power. For example, "switch-up" to Wi-Fi is to increase available bandwidth, and "switch-down" to Bluetooth (and power off Wi-Fi) is to conserve energy.

Footprint [2] exploited the cellular information (cellular tower IDs, signal strength) to guide Wi-Fi interfaces to scan the available APs, and reduced the number of unnecessary scans. Blue-Fi [1] aims to predict the availability of the Wi-Fi connectivity by using a combination of Bluetooth contact-patterns and cell tower information.

Our work is similar to Blue-Fi and Footprint, while we use Zigbee radio and emphasize the collaboration among mobile devices.

III. ZIGBEE BASED COLLABORATIVE AP DISCOVERY

A. Overview

We first investigate a simple scenario to conveniently describe the collaborative AP discovery process.

As shown in Figure 2, there are three APs in an area (purple area) — AP1, AP2 and AP3, and three dotted lines sketching

the three APs' coverage area and dividing the entire area into seven sub-areas. We assume that at the beginning there are no mobile devices in this area, and then:

- Mobile device A (A hereinafter) enters Area1 and requests wireless connection. A will first check its local database to see whether there is available AP information. If the result is no, and there are no other mobile devices to share AP information at that time, A has to invoke its Wi-Fi scanning functionality to scan the available APs nearby, and will obtain AP1's information. A then connects to AP1, records AP1's information into its local database and periodically broadcasts AP1's information via its Zigbee interface from now on.
- Then B and C enter area2 and area6, respectively. Like A, B and C will check if there is available AP information in their databases before scanning for available APs when they have a connection request. In this case, the algorithm itself can guarantee that B and C will not obtain AP1's information (will be discussed in section 3.2.1 in detail). The AP information updating scheme will periodically check the effectiveness and validation of AP information saved in local database and remove invalid AP information. For the above reasons, B and C will turn on Wi-Fi scanning functionality to scan and connect to AP2 and AP3 respectively, and then periodically broadcast AP2 and AP3's information via Zigbee interfaces hereafter.
- A few minutes later, D enters Area1, and will receive AP1's information if D is in the communication range of A. D records it in its local database, and broadcasts the information to the nearby mobile devices based on the selectively broadcasting scheme (discussed in detail in section 3.5). Then, D can directly connect to AP1 without Wi-Fi scanning. If D does not receive AP1's information, D will turn on its Wi-Fi scanning functionality to search the available APs. In fact, the probability for D to receive AP1's information increases with the increasing number of devices in the area.

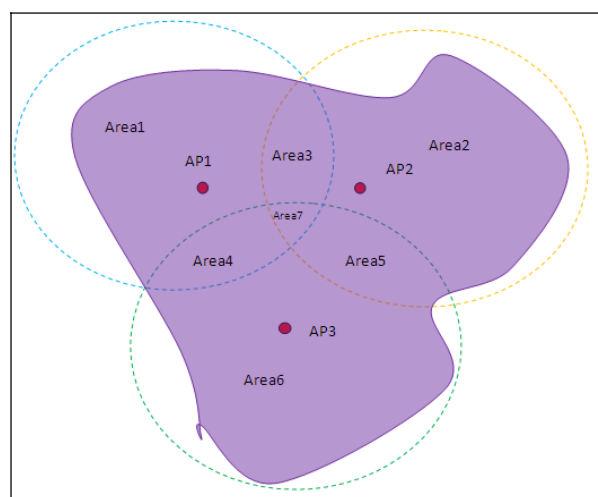


Figure 2. A simple scenario

- Mobile devices in area3, area4, area5, area6 and area7 will obtain more than one AP's information. When they have connection requests, they will select an optimal AP based on the AP selecting scheme (discussed in detail in section3.5) and associate with it.

From the above discussions, we can conclude that, in a specific area, ZCAD just requires a few devices to invoke Wi-Fi scanning to gain the APs' information within this region and share them via Zigbee interfaces. After a short period of time for information diffusion, all the devices in this region can obtain the AP information, optimally choose an AP, and significantly reduce the power consumption.

B. Algorithm Description

In this section, we provide a detailed description of ZCAD.

1) Basic Data Structures

We first introduce three important data structure:

- APInfo (AP Information): APInfo is used to describe the basic information necessary for connecting APs, whose structure is as follows: {wlan_ssid, wlan_name, wlan_type, signal_strength, ipv4_type, wlan_security, wlan_hidden, connecting_time}.
- APRec (AP Record): APRec consists of an APInfo and two other members, whose structure is as follows: {APInfo, lifetime, count}. The *lifetime* field represents the lifetime of the AP record which is used to guarantee the effectiveness and validation of AP information; e.g., an AP information will be deleted from mobile devices if its lifetime expires. The *count* field records the repeated times that an AP information is received by the device during a transmission cycle and is used for AP selectively broadcasting scheme.
- APList (AP List): APList is a list of all the locally saved APRec.

2) Algorithm Flow

The Figure 3 shows the flow-process diagram of ZCAD.

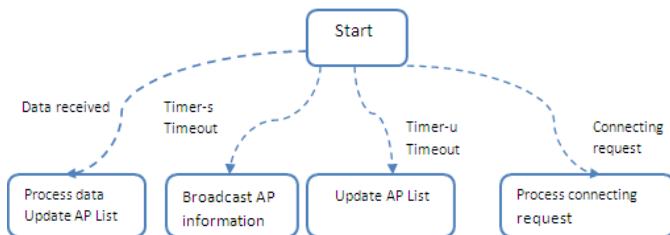


Figure 3. Algorithm Flow Diagram

ZCAD mainly consists of three parts:

- Updating AP List: We developed an AP List Updating algorithm to guarantee the effectiveness and validation of AP information. Whenever a mobile device receives AP information from a Zigbee interface, the algorithm will first check whether there exists an APRecord in its local database. If yes, the algorithm resets the APRecord's *lifetime* to 0 and increases its *count* value by one. If not, the algorithm generates a new APRec,

copies the received APInfo to its APInfo field, and initializes the *lifetime* field and the *count* field with zero. Meanwhile, a timer-u (a timer) is used to control the effectiveness of APInfo: whenever a timer-u (a timer) goes off, the algorithm will scan the AP List and remove all the AP Records whose lifetime expires. We will make a detailed discussion on the effectiveness of AP information in section 3.3.

- Sharing AP Information: The mobile devices will periodically broadcast the AP Information saved in their local database to share it with the other mobile devices. To efficiently finish the task, we propose an AP information selectively broadcasting algorithm which aims to reduce the total amount of data sent while guarantee correctly diffusing AP information by filtering out invalid AP information. The AP information selectively broadcasting algorithm consists of the following steps: Whenever a time-s (a timer) expires, the algorithm will first scan the AP List, pick out the APRec whose *count* is smaller than 3 and the signal level value of their AP information is greater than 1, then broadcast these AP information. According to the definition of *count* field of APRec, if the *count* is greater than 3, which means there are more than 3 mobile devices nearby having broadcasted the same AP information, there is no need for this device to broadcast this AP information anymore.
- Processing Connection Request: Whenever there is a wireless connection request, the algorithm will first check if the AP List is null. If yes, switch on Wi-Fi scanning functionality to search the available APs; if not, select an AP in the APList according to the AP selecting algorithm. We will discuss the AP selecting algorithm in section 3.4.

C. Guaranteeing The Effectiveness and Validation of AP Information

As discussed above, the validation and effectiveness of the AP information is critical to ZCAD. AP information is considered as effective and validate if the mobile devices can successfully associate with the AP by this AP information. The AP information sharing algorithm ensures that for each of the AP information that received by Zigbee interfaces, there exists at least one device in this area that has successfully associated to the corresponding AP. This will guarantee the validation of the AP information to some extent. Furthermore, if there exists an AP to which no device is connected, the corresponding APRec will be deleted based on the AP information updating algorithm.

D. AP Selecting Algorithm

The AP selecting algorithm target to select the optimal AP based on the obtained AP information. We adopt a parameter P to measure the priority of an AP: $P = SS/CT$, where SS is the AP's signal strength and the CT is connecting time (the time interval between the time to connect an AP and the time having connected the AP). The AP with maximum P value is considered as the optimal AP.

IV. EVALUATION

In this section, we first evaluate the power consumption of ZCAD and compare it with the normal Wi-Fi mode, and then we test the effectiveness of our AP selecting algorithm. Finally, we evaluate the AP information broadcasting algorithm by comparing with the traditional flooding algorithm.

A. Power Consumption

We first measure the power consumption of Zigbee interface when it is sending data. Experimental Scenario: a Nokia N810 equipped with a μ SD card periodically broadcasts 10 APRec records from its local database at 5 different frequencies: 1s, 3s, 6s, 9s, $+\infty$ ($+\infty$ means never sending data), and we use Nokia Energy Profiler tool to record power consumption within 2 minutes in real time. The results are shown in the following figures.

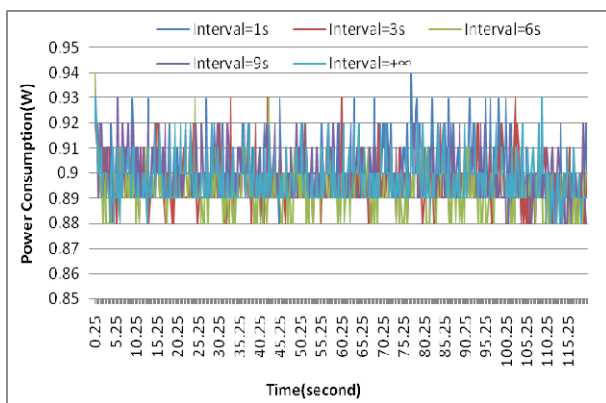


Figure 4. Power consumption of Zigbee interface at different sending frequency

As shown in Figure 4, there are no significant differences in the power consumption among the 5 cases, and all the power lines fluctuate between 0.88w and 0.94w. This means that sending/receiving data using Zigbee interface has no significant impact on the power consumption of the whole system, which indicates that the power consumption of Zigbee interface is extremely low.

We compare the power consumption in ZCAD mode (Zigbee mode hereinafter) with commonly used Wi-Fi mode (Wi-Fi mode hereinafter), in which a Wi-Fi interface scan and then connect to an AP, and the results is shown in Figure 5. The comparison is conducted by recording the real-time power consumption of two N810s within 2 minutes: we use one N810 connect to AP in Wi-Fi mode and another in Zigbee mode.

In Figure 5, the blue line and the red line indicate the real-time power consumption of Wi-Fi mode and Zigbee mode respectively. There are two distinct energy peaks in Wi-Fi mode: the first one is from about the 22th second to the 28th second, i.e., the Wi-Fi scanning stage; another one is from about the 32th second to the 47th second, i.e., the Wi-Fi association stage. Unlike Wi-Fi mode, in Zigbee mode, as the mobile devices directly connect to AP using the AP

information received from Zigbee interface and skip the scanning stage, there is only one energy peak.

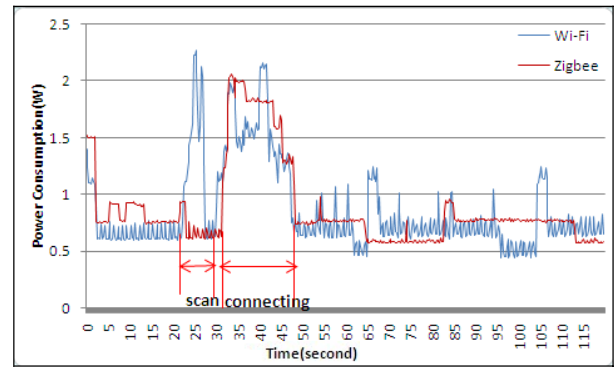


Figure 5. Comparison of power consumption between zigbee mode and Wi-Fi mode

The result in Figure 5 reveals that ZCAD can effectively reduce the power consumption of Wi-Fi interfaces by decreasing the number of energy peaks resulted from Wi-Fi scanning.

B. Evaluating AP Selecting Algorithm

The AP selecting algorithm in ZCAD targets to select the optimal AP based on the received AP information (e.g., access time, APs' signal strength) shared among mobile devices. The critical point in this algorithm is whether the AP information is effective and valid for AP selecting. The actual connecting time and signal strength (signal level) from multiple mobile devices may be very different due to their different locations. If the shared AP information is inaccurate, the AP selection algorithm will generate incorrect results, which will badly affect the system performance. Considering that, we examine the effectiveness of the AP information for AP selection. The experimental scenario is: we use a N810 to select an optimal AP according to our selecting algorithm and connect to the AP, and record the actual connecting time, signal level. The logged connecting time, signal level of the selected AP, the maximum and minimum value of connecting time and signal level logged in local database are used as well. Repeat the experiment 12 times at 12 different places. The results are shown in Figure 6 and Figure 7.

Figure 6 reveals that there is almost no difference between the actual connecting time and the logged connecting time of the selected APs, while the actual connecting time is close to the minimum connecting time.

Similarly, the differences between the actual signal level and the logged signal level are trivial. In a word, these results reflect the effectiveness of our selecting algorithm.

C. Evaluating AP Information Selectively Broadcasting Algorithm

The AP information selectively broadcasting algorithm in ZCAD aims to reduce the amount of data sent while guaranteeing the correct diffusion of AP information, in order to further reduce power consumption.

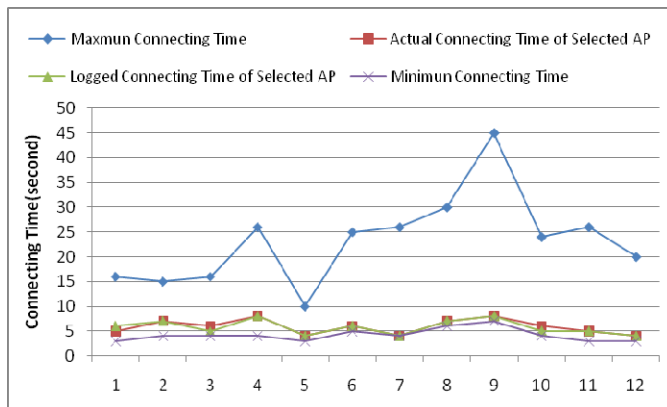


Figure 6. Connection time

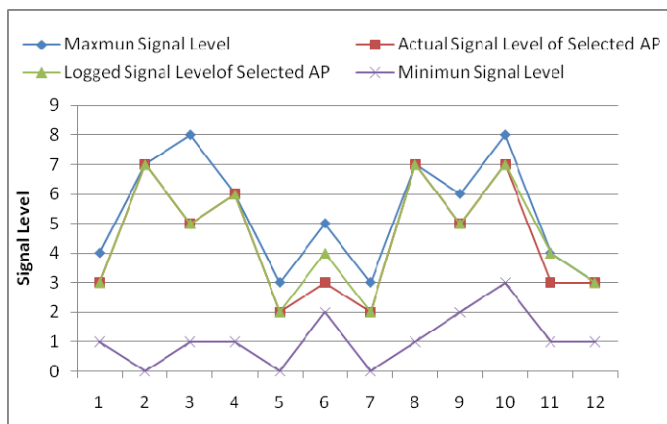


Figure 7. Signal level

The power consumption of both the traditional flooding algorithm and our AP information selectively broadcasting algorithm is compared, and the results are shown in Figure 8 and Figure 9. In the traditional flooding algorithm, the system broadcasts all locally stored AP information.

The experimental scenario is: one N810 adopts selective AP information broadcasting algorithm and another uses flooding algorithm. This experiment was conducted in a building with 8 APs and the sending interval is set to 3s. We record the total amount of data sent and the power consumption of two N810s within 1 minute.

As shown in Figure 8, at the beginning, the amount of data sent rises as the amount of received AP information increases; during the beginning period of time the amount of data sent by the two N810s is almost the same. The differences turn out as the received AP information gradually reaches the maximum, which means all the 8 APs' information has been received and stored in its local database. Hereafter, for the flooding algorithm, due to broadcasting all the locally stored AP information, the amount of data sent keeps the maximum, while our selectively broadcasting algorithm, owing to filtering out part of invalid AP information, the amount of data sent gradually decreased and finally reaches a stable level.

Figure 9 shows the real-time power consumption of the 2 N810s during this experiment. These two lines in Figure 9 reveal that there are no significant differences of power consumption between these two N810s, which reflects the fact from another aspect that the power consumption of Zigbee interface is very low and almost has no impact to the whole system's power consumption.

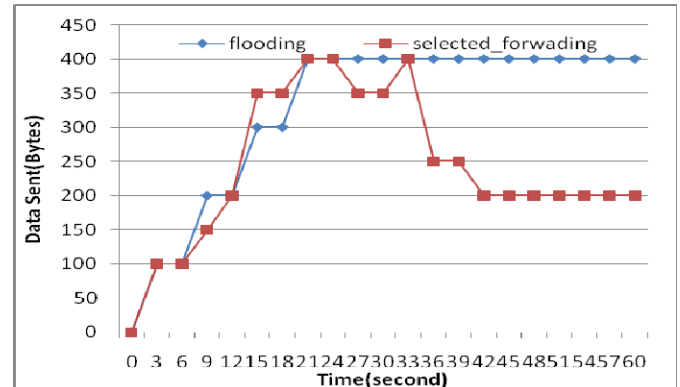


Figure 8. Comparison of the amount of data between selectively broadcasting and the traditional flooding

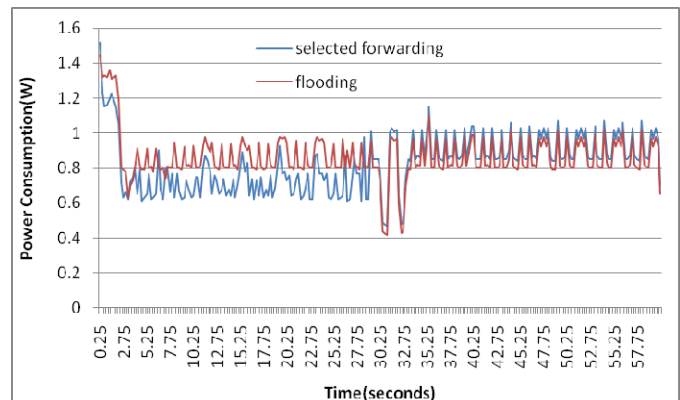


Figure 9. Comparison of power consumption between selectively broadcasting and traditional flooding

V. CONCLUSIONS

In this paper, we proposed a Zigbee based Collaborative AP Discovery scheme (ZCAD) to improve the energy efficiency of the Wi-Fi interface by sharing AP information among mobile devices using Zigbee channels. ZCAD consists of an AP information updating algorithm to guarantee the validity of AP information, an AP information selectively broadcasting algorithm to efficiently share AP information among mobile devices, and an AP selecting algorithm for the mobile devices to select an optimal AP. ZCAD enables mobile devices to directly associate with APs without scanning, therefore reduces the power consumption of Wi-Fi interfaces. Experimental results reveal that ZCAD can significantly decrease the number of scanning for AP discovery and therefore effectively reduce the power consumption of Wi-Fi

interfaces. ZCAD will be possibly deployed on the future Nokia mobile devices.

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