Efficient Approach for Energy Saving using Multihop Nodes for Portable Devices

M. Pavithra, P. Sowmiya, N. Shanthini and E. Haripriya

Abstract--- *One of the most widely used wireless communication standards is a Wireless Local Area Network (WLAN) (IEEE 802.11). However, WLAN has a serious power consumption problem. In the paper, a novel energy saving approach is proposed that exploits the multiradio feature of recent mobile devices equipped with WLAN and Bluetooth interfaces. The work is based on clustering. In the work, a cluster is a Bluetooth Personal Area Network (PAN), which consists of one cluster head and several regular nodes. The cluster head acts as a gateway between the PAN and the WLAN, enabling the regular nodes to access the WLAN infrastructure via low-power Bluetooth. The paper presents a distributed clustering protocol, Cooperative Networking protocol (CONET), which dynamically reforms clusters according to each node's bandwidth requirement, energy use, and application type. Unlike existing, the new approach also works for multi-hop clustering also.*

Index Terms--- *Wireless Communication, Protocol Architecture, Multiradio, Energy Efficiency, Clustering*

I. INTRODUCTION

WIRELESS local area network (WLAN) , or IEEE 802.11, has created a wave of popular interest because of its sufficient bandwidth and well-constructed infrastructures. However, a serious problem of WLAN is its considerable energy consumption, energy consumed by WLAN interfaces accounts for more than 50 percent of the total energy consumption in hand-held devices and up to 10 percent in laptops . Because mobile devices are usually driven by limited battery power, it is essential to devise novel solutions to reduce the power consumption due to the WLAN interface without degrad- ing its performance.

About 70 percent of smart phones in the market have a Bluetooth interface as a secondary radio for personal area networking. The Bluetooth standard is primarily designed for low-power consumption, requiring only about a 10th of the WLAN power . However, because of its limited power, Bluetooth supports a low bandwidth of only 2 Mbps (version 2:0 + EDR), with a short range of 10 meters (class 2). In this work, we explore the idea of using this coexistence of high-power/high-bandwidth WLAN and low-power/low-bandwidth Bluetooth in a single mobile platform to solve the power consumption problem in WLAN-based communication systems.

Several previous works have exploited Bluetooth as a secondary radio to reduce the overall power consumption. Bluetooth is mainly used to provide always a connected channel between mobile devices and the WLAN access point (AP). In On Demand Paging and Wake on Wireless , mobile devices and the AP exchange control messages, e.g., wake-up messages, via low- power channels.[1]This allows a mobile device to turn off the WLAN interface when it is not being used. CoolSpots [6] and SwitchR use Bluetooth more actively to lengthen the power-off time of WLAN: Bluetooth is used not only for the wake-up channel, but also for data communication when applications demand low data rates. WLAN is powered up only when the data rate reaches the Bluetooth limit. However, these approaches usually assume that APs also have both WLAN and Bluetooth interfaces (and specialized software to control them). This assumption guides the hardware and software modifications to our wireless infrastructures.

Unlike these previous works, our approach is based on clustering. Clustering is commonly used in sensor networks for network scalability, load balancing, data aggregation, or energy efficiency. In our work, clustering makes nodes (i.e., mobile devices) that share their WLAN interfaces with each other. Fig. 1 depicts the concept of our approach and compares it to the previous approaches. As shown in Fig. 1b, a cluster is a Bluetooth Personal Area Network (PAN) that consists of one cluster head (CH) and several regular nodes (RNs). CHs are responsible for coordination among the nodes within their clusters and the forwarding of packets from the PANs (clusters) to the WLAN, and vice-versa. CHs keep their WLAN interfaces on to provide links to the WLAN AP, allowing RNs to use only Bluetooth and turn their WLAN interfaces off in order to save energy.

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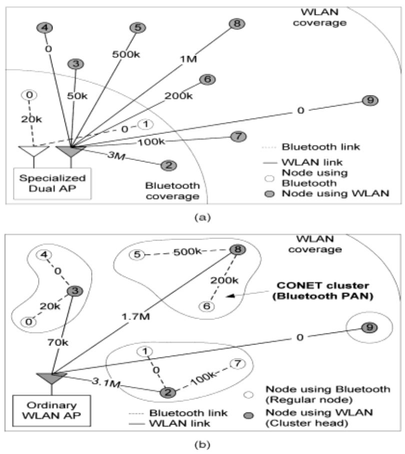

Fig. 1: A comparison of the previous approaches and our approach for the same network of 10 nodes. The numbers of the links (straight lines) represent data rates in bits per second. 0 indicates that the node is in the idle listening state. (a) Previous approaches based on the dual AP. Only 2 (node 0 and 1) of 10 nodes can communicate via Bluetooth. The others should keep their WLAN interfaces on due to the limited coverage (from nodes 3 to 9) and bandwidth (node 2) of Bluetooth. (b) Our approach based on clustering. Ten nodes are grouped into four clusters, and each cluster meets the bandwidth requirements of all nodes. Six regular nodes can save energy.

Clustering is periodically performed in a distributed manner based on the energy uses and bandwidth requirements of the nodes.

In this work, clustering is performed independently of WLAN APs. Therefore, our approach does not require modifications to existing infrastructures (i.e., ordinary APs can be used), while the previous approaches require specialized APs with dual radios. Moreover, we solved the scalability problem of the previous works, as shown in Fig. 1a. Because of the large difference between the communication ranges of WLAN and Bluetooth, only a few devices close to the dual AP can use the low-power radio. In our case, on the other hand, since clusters can be created anywhere, most devices can obtain the benefit of energy saving, as shown in Fig. 1b.

One unique requirement which distinguishes our ap- proach from the traditional clustering problem in sensor networks is that, unlike sensor nodes which are left unattended after deployment, mobile devices (e.g., PDAs) are arbitrarily controlled by their users. This necessitates the consideration of node mobility as well as a large variance of bandwidth requirements of various applications. Moreover, because all devices have equal significance, rotating the CH role among all devices is necessary to distribute energy consumption. Mobile devices also can be turned off at any time and powered again depending on the users' needs, which necessitates the consideration of unexpected link failures.

This paper presents a distributed clustering protocol, Cooperative Networking protocol (CONET). CONET has four main objectives:

1. improving the energy efficiency of wireless net- works by exploiting a secondary radio,
2. dynamically configuring clusters to meet the band- width requirements of all nodes,
3. producing well-distributed cluster heads, and
4. minimizing control overhead.

CONET dynamically clusters the network according to each node's bandwidth, energy, and application type. We have implemented the CONET prototype using wearable com- puters to evaluate its performance on real hardware systems. We also simulate CONET for large networks of more than 100 mobile nodes and evaluate the performance. Both results demonstrate that CONET is effective in reducing the power consumption of WLAN-based commu- nication systems.

The remainder of this paper is organized as follows:

Section 2 describes the problem. Section 3 presents the CONET protocol, and Section 4 discusses the issues in implementation. Section 5 shows the effectiveness of CONET via real hardware evaluation and simulations. Section 6 briefly surveys related works. Finally, Section 7 gives concluding remarks and directions for future research.

II. PROBLEM STATEMENT

The mobile devices that we consider in this paper are popular user terminals, such as smart phones or wearable computers. For the rest of this paper, we simply refer to a mobile device as a node. We assume the following proper- ties about the nodes and wireless networks:

1. Each node has one WLAN interface (primary) and one Bluetooth interface (secondary).
2. There is at least one WLAN access point in the field.
3. Each node can communicate with the access point using its WLAN interface, regardless of its location and time.
4. The WLAN access points do not have Bluetooth interfaces. This is typical for most existing wireless environments. Therefore, the previous approaches are inapplicable.
5. Each node i knows the total bandwidth required, $NeedBW_i(t)$ and the free bandwidth of its Bluetooth link, $FreeBW_i(t)$.
6. Each node i can measure its residual energy $E_i(t)$

7. All Bluetooth interfaces have the same communica-tion range.

The final goal of our CONET is to reduce the power consumption in wireless networking applications. For this purpose, we first classify popular applications into two types: group networking and individual networking. Next, we propose a general clustering protocol that considers both application types.

Group networking. In this case, a group of nodes have a common goal and need to prolong the group lifetime to achieve that goal. The group lifetime can be defined as the time elapsed until the first node in the group depletes its battery. For example, let us assume that some friends are playing network games together using their nodes. In this case, the maximum time during which they can play together will depend on the node with the lowest remaining battery. CONET can be applied here to prolong the group lifetime: the users can play for more time by rotating the CH role and letting nodes with lower energies be RNs and nodes with higher energies be CHs for most of the time.

.Individual networking. In this case, we consider unrelated individuals running their own applica- tions (i.e., no common goal), even when they are geometrically close to each other. In a subway train, for example, many people may use their mobile nodes simultaneously, but each of them is likely to have different purposes: one may visit websites or one may just wait for incoming messages while keeping her wireless interface on. Cooperative clustering can also be applied to this case for energy conservation. An important requirement in this case is that the benefit of each node gained by coopera- tion should be equal for all individuals because, unlike group networking, no one will want to spend more energy just to help unrelated users. Therefore, CONET should distribute the advantages of cluster- ing in a fair way for these types of applications.

Our goal is to design a general clustering protocol that satisfies the requirements of the above application types. To accomplish this, we separate cost functions from the clustering algorithm and provide two cost functions for each of application type. Users can select proper cost functions for their applications. Depending on the selected cost function, a different set of nodes is selected as cluster heads to meet the user requirements. Also, the following requirements must be met:

1. Clustering should be completely distributed. Each node independently makes its decisions based only on local information.

2. For each cluster cj , the sum of bandwidth require- ments of all regular nodes within the cluster must not exceed the maximum data rate of Bluetooth RB ,i.e.∑RNk€cjNeedBWk(t)<=ARB where RNk is the regular node of) is the required bandwidth for node k at time t.

At the end of the clustering process, each node should be either a cluster head or a regular node that belongs to exactly one cluster.

4. Clustering should be efficient in terms of processing complexity and message exchange.

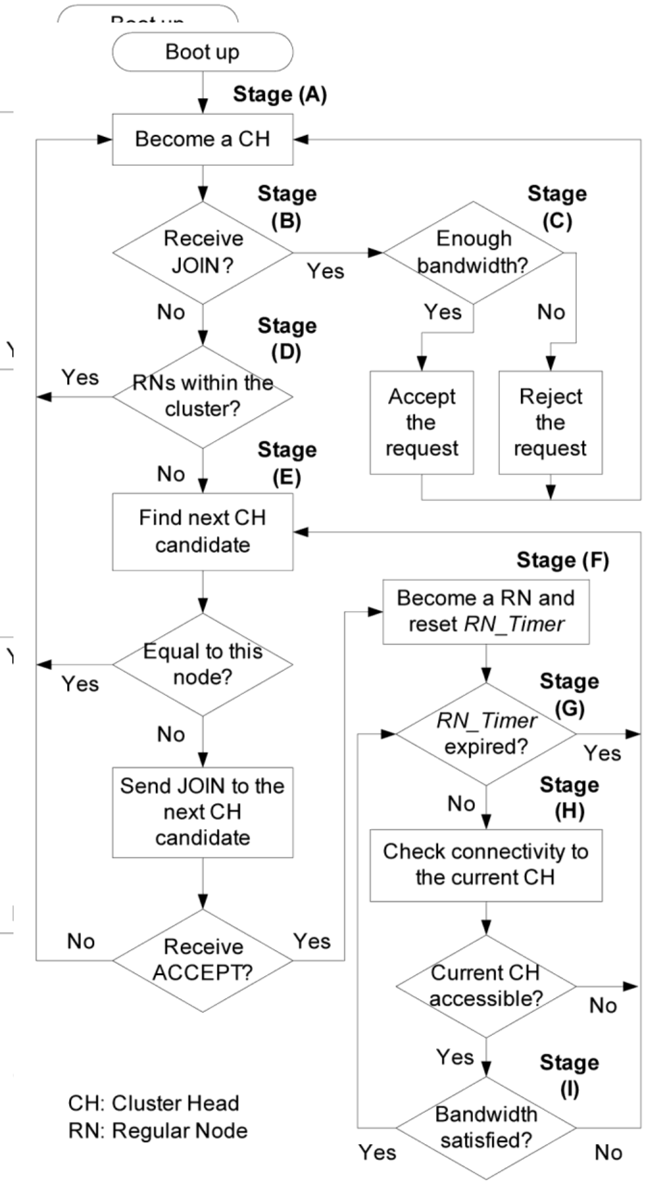

Fig. 2: Flow Chart of CONET Clustering Protocol

III. THE CONET PROTOCOL

This section describes CONET in detail. First, we present the protocol design. Next, we define the parameters and cost functions.

- *Protocol Operation*

Fig. 2 shows the details of our protocol. Nodes exchange clustering messages via Bluetooth. For easy understanding, we describe our protocol based on the example shown in Fig. 3 with a group networking scenario: nodes 1, 2, and 3 have a common collaborative task and attempt to maximize the group life time.

- *Cluster Head Advertisement*

When a node is newly booted up, it becomes a CH, as shown in the flow chart (Fig. 2). Assume that all three nodes of the example shown in Fig. 3 are booted up at the same time. Then, since all of them independently become CHs, three clusters are created (Fig. 3a).

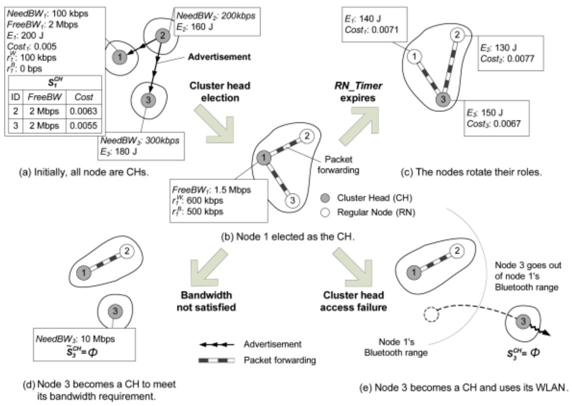

Fig. 3: An Illustrative Example of CONET Protocol Operation

member of each cluster is the cluster head itself. Like these channels (T WI and T BI , respectively) during a period of time clusters, a cluster which has no RNs is called a trivial cluster, T , each node i can estimate its FreeBW W

and FreeBW B and the head of the trivial cluster is called a trivial cluster head (tCH).

When a node becomes a cluster head its starts to advertise its resource information periodically(say every 200msec) via low power Bluetooth. It repeats advertising as long as it is a CH. The advertisement message of node i contains the clustering cost Ci , the amount of bandwidth available for packet forwarding F reeBWi , and some required information, such as the ID and the network address. Each node manages a set SCH , which stores the information advertised by neighboring CHs.

Because CHs act as gateways that connect Bluetooth nodes And RNs to the WLAN access point, FreeBWi of CH i should be Rmar is a predefined constant used to maintain the free bandwidths to be slightly lower than the bandwidth actually available. It is necessary to switch between radio interfaces dynamically based on the current data rate. Later, in this section, we explain the details of interface switching. Our current design assumes that RW is a predefined constant, but the IEEE 802.11 standard the smaller value between FreeBW W and FreeBW B , the provides multiple transmission rates depending on Signal-amount of free bandwidth on Bluetooth and WLAN links, respectively. To estimate the free bandwidth on a wireless link, we can use well-studied bandwidth estimation techniques. For example, we can estimate the free bandwidth using the idle channel time as proposed in. A channel is considered to be idle if the node is not sending or receiving data through the channel and a carrier or interference signal is not sensed on that channel. By monitoring the idle channel times of WLAN and Bluetooth to-Noise Ratio (SNR). We plan to improve CONET to support multiple rates in our future research.

Although only CHs advertise their resources, RNs also measure free bandwidth for cluster head election (discussed later). However, because RNs use only Bluetooth, their FreeBW W values are always zero, and thus, meaningless. Therefore, the free bandwidth of RNs should be set to FreeBWB.

Note that CONET does not limit the bandwidth estimation technique. It can also operate with other techniques, with minor modifications.

- *Responding to Join Requests*

In stage (B) of Fig. 2, each CH waits for JOIN requests from other nodes for a short time (say, 1 second). The JOIN message of node i includes the amount of required bandwidth NeedBWi. Upon receiving a JOIN message, the CH goes to stage (C) and compares its FreeBW with the sender's NeedBW. If the CH has a sufficient amount of free bandwidth for the sender (i.e., FreeBW _ NeedBW), it will accept the request, but, otherwise, reject it. After responding to the request, the CH returns to the initial stage. The sentence, "Become a CH," in stage (A) means "keep the CH role" for the nodes that are already CHs. At the initial moment shown in Fig. 3a, because no node has sent a JOIN message yet, all the nodes go down to stage (D).

- *Cluster Head Election*

When there is no JOIN request, the CH counts the number of RNs within its clusters (stage (D) in Fig. 2). If there is at least one RN in the cluster, the CH returns to the first step and keeps its current role. This allows RNs to select their next CHs by themselves, which is necessary for network stability: If CHs stop their roles of packet forwarding regardless of the associated RNs, the RNs will occasionally lose their links to the WLAN access point. Furthermore, clusters will be reformed quite frequently if CHs ignore the status of each RN, such as the first association time (the time at which the RN has joined).

The chance for energy saving is given to trivial CHs (tCHs), which turned out to have no RNs within their clusters at the end of stage (D). A tCH selects its next CH by itself. In stage (E), each tCH calls the FIND_NEXT_CH procedure, which presents the CH election process of CONET. Assume that node i calls FIND_NEXT_CH. It then executes the following procedure: For example, let us assume that node 1, which is a trivial CH at the moment depicted in Fig. 3a, reaches stage (E) and calls the FIND_NEXT_CH procedure. First, node 1 prunes the CHs that cannot satisfy its bandwidth demand NeedBW1 from election. If the node runs constant bit rate applications, such as VoIP, NeedBW1 can be determined explicitly. However, in general TCP-based applications, it is not trivial to predict the amount of needed bandwidth in advance because TCP will match its sending rate to the available capacity. In this case, we set NeedBWi to the node's current data rate (rWi if the node is a CH, rBi otherwise). The node will become an RN (switch to Bluetooth) only if the free bandwidth on the link to the CH is higher than its current data rate.

Even though all nodes estimate FreeBW using (3), the estimation results of two neighboring nodes could be different due to the limited radio range [17]. For example, let us assume that there is a hidden flow on the left side of node 1 in Fig. 3a, which is in node 1's radio range, but out of nodes 2's radio range. In this case, FreeBW1 will be estimated to be smaller than FreeBW2 because the flow only interferes the idle channel time of node 1. Therefore, the maximum bandwidth between nodes 1 and 2 is bounded by the smaller value FreeBW1. This indicates that the free bandwidth on the link between nodes i and k should be the minimum value between FreeBWi and FreeBWk, i.e., MINðFreeBWi; FreeBWkÞ. In this example shown in Fig. 3a, because there is no hidden flow and all nodes have equal available bandwidths of 2 Mbps, neither node 2 nor 3 is pruned when node 1 calls the FIND_ NEXT_CH procedure. Therefore, node 1's pruned CH set SCH 1 is exactly the same as the original CH set SCH 1 .Next, node 1 selects the lowest cost node among the nodes in ~ SCH1 and itself. For simple explanation, let us assume that the cost of each node i, Ci, is simply the reciprocal of its residual energy Ei, i.e., Ci ¼ 1=Ei.2 The purpose of this cost function is to select the node with the highest residual energy as the CH for other low-energy nodes. Because node 1 has the lowest cost in the case of Fig. 3a, it returns to stage (A) and repeats the above processes. Similarly, nodes 2 and 3 elect node 1 as their CH and send JOIN messages to it. As their requests are accepted by node 1, they go to stage (F) and become the RNs of node 1. Finally, nodes 1, 2, and 3 are clustered together, as shown in Fig. 3b.

- *Role Switching*

It is necessary to rotate the CH role regularly to balance the energy consumption among all nodes. To do so, each RN has a timer, RN_Timer, which expires every TRN seconds. When the timer expires, the RN goes to stage (E) again and calls the FIND_NEXT_CH procedure to elect its next CH. Depending on the election result, the RN itself becomes a new CH or joins one of the existing clusters, including its current cluster. The transition from Figs. 3b and 3c shows the cluster reformation due to the timer expiration. Let us assume that since the first cluster is created (Fig. 3b), the RNs, nodes 2 and 3, have consumed 30 Joules, while the CH, node 1, has consumed 60 Joules, regardless of their data rates.3 As RN_Timer independently expires in the RNs, they move from stage (G) to stage (E) in Fig. 2. Then, node 3 finds out that it has the lowest cost among the nodes. Thus, it becomes a CH and node 2 joins the new cluster. At this moment, node 1 eventually becomes a trivial CH because no node is associated to it. Then, node 1 goes to stage (E) and finds out that node 3 is the lowest cost CH. Thus, it joins node 3, resulting the new cluster structure, as shown in Fig. 3c. By regularly switching roles in this manner, energy consumption can be distributed.

- *Recovering Cluster Head Failures*

Due to the mobility of nodes, if the distance between an RN and its CH becomes longer than the Bluetooth range, the RN will not be able to access its CH anymore. The same situation happens when users intentionally turn off Blue- tooth or WLAN (or both) interfaces or shut down their nodes. In these cases, the RN immediately goes to stage (E) in Fig. 2 to find its new CH. To do so, each RN continuously checks the connectivity to its current CH in stage (H).

For example, as shown in Fig. 3e, as node 3 goes out of the Bluetooth communication range of its current CH (node 1), it loses the connection to the CH. As soon as it detects the CH failure in stage (H), it goes to stage (E) and calls the FIND_NEXT_CH procedure. In the case of Fig. 3e, because node 3 has no neighboring CHs, it becomes a CH and continues its previous communication using its WLAN interface.

- *Satisfying Bandwidth Requirements*

Unlike the tiny nodes in sensor networks, the nodes considered in this work have a large variety of applications, resulting in time-varying bandwidth requirements with huge variations. Therefore, nodes should selectively use either Bluetooth or WLAN depending on the requirements.

To do so, each RN i associated to CH k monitors the amount of free bandwidth on the link between nodes I and k, i.e., MIN(FreeBWi; FreeBWk), and the current data rate rBi . When NeedBWi is known explicitly (i.e., CBRapplications), the RN directly compares the current data rate with NeedBWi to check whether its bandwidth requirement is satisfied or not. If rBi < NeedBWi, then it goes to stage (E) of Fig. 2 to find a new CH which can meet its bandwidth demand. In general TCP applications, the amount of bandwidth needed is not determined explicitly. In this case, node I assumes that its NeedBWi is equal to rBiand controls radio interfaces to satisfy rBi . The free bandwidth is estimated to be slightly lower than the actually available bandwidth ((1)-(3)) so that the value of MIN(FreeBWi; FreeBWk) will cross zero and become negative as rBi reaches the capacity limit. In this case, i.e., MIN(FreeBWi, FreeBWk) < 0, the RN goes to stage (E) of Fig. 2 to find a new CH. Otherwise, it returns to stage (G) and repeats the above processes. This situation is illustrated in Fig. 3d: as NeedBW3 increases to 10 Mbps, node 3 finds out that the current CH (node 1) cannot meet this requirement (stage (I) of Fig. 2). Thus, node 3 goes to stage (E) to find a new CH, but no node can satisfy the requirement of 10 Mbps.

- *Application Types and Cost Functions*

In this section, we present two cost functions designed for group networking.

- *Group Networking*

As described in Section 2, the main objective of group networking is to prolong the group lifetime. In sensor networks, one popular cost function used to maximize the network lifetime is primarily based on the residual energy of each node [11], [13], e.g., (maximum energy)/(residual energy). This cost function distributes energy dissipation over the network particularly wellwhenthe power consumption rates are equal for all nodes. In CONET, however, a variety of nodes typesmadeby different venders are clustered together, breaking the homogeneity of the power consumption rate. Therefore, our cost function for the group networking case is based on each node's estimated lifetime, the estimated time for a node to survive in the future. We define the cost of being a CH for node i at time t, Ci(t), as follows: where Li(t) is node i's estimated lifetime. We assume that each node i knows its current power consumption Pi(t) and residual energy Ei(t) Then, the lifetime estimation is based on the moving average of the current and past power usage with weight , where Pi(t) represents the future power consumption estimated at time t. Once Pi(t) has been estimated, the node can calculate its Li(t) .

IV. RELATED WORK

Many previous studies have investigated techniques that reduce the energy consumption due to WLAN interfaces in single radio mobile devices. They optimize the power consumption at various layers, such as the application layer , transport/network layer , and MAC layer. The IEEE 802.11 standards also define several low-power modes, such as PSM in the legacy 802.11 and Automatic Power Save Delivery (APSD) in 802.11e . They allow nodes to keep their WLAN cards in the sleep state when they do not have to communicate and switch to active state periodically (PSM) or at application-specific instants of time APSD to retrieve data buffered in the access point.

Although the majority of the WLAN interface's circuitry is turned off in the sleep state, the base power consumption for the minimal host card interaction and state transition is not negligible, which is typically 200-400 mW. On the other hand, CONET allows RNs to completely turn off their WLAN interfaces and use only Bluetooth. Moreover, since Bluetooth also supports low-power modes, such as sniff mode , which operate in similar manner to PSM but consume an order of magnitude less power than PSM (e.g., 25mW), RNs can save more energy using Bluetooth low power modes. Of course, CHs can operate using PSM or APSD to communicate with the access point, resulting in lower average power consumption than PSM or APSD. Some advanced WLAN chipsets dramatically reduce the idle power consumption, but require cost and time for hardware upgrade or worldwide deployment. As a result, the majority of today's hand-held products still have power consumption problem due to the WLAN interface.

V. CONCLUSION AND FUTURE WORK

In this paper, we have presented CONET, a bandwidth aware and energy-efficient clustering protocol for multiradio mobile networks. CONET uses Bluetooth to reduce the power consumption of WLAN in mobile devices. It dynamically reconfigures the clusters based on the bandwidth requirements of applications to avoid the performance degradation. We have classified the applications into two cases: group networking and individual networking. CONET runs the same election algorithm for both cases, but uses different cost functions. CONET maximizes the group lifetime for the group networking case and fairly distributes the energy gain among all nodes for the individual networking case. One key feature of our approach is that it does not require modifications to existing wireless environments, paving the way to easy deployment. Although this paper describes CONET based on WLAN/ Bluetooth, we believe that it can be easily extended to other interface combinations, such as WiMAX/Bluetooth. CONET can be applied to advanced types of sensor networks in which nodes have multiple radio interfaces Although we have only provided algorithms for onehop clustering, we can extend our protocol to support multihop clustering. This can be achieved by applying general multihop clustering algorithms, such as Max-Min D-Cluster formation .

REFERENCES

[1] Jong-Woon Yoo, Kyu Ho Park, "A Cooperative Clustering Protocol for Energy Saving of Mobile Devices with WLAN and Bluetooth Interfaces., 2011.

[2] Y. Agarwal, R. Chandra, A. Wolman, P. Bahl, K. Chin, and R. Gupta, "Wireless Wakeups Revisited: Energy Management for VoIP over Wi-Fi Smartphones," Proc. ACM MobiSys, Pp. 179-191, 2007.

[3] Y. Agarwal, R. Chandra, A. Wolman, P. Bahl, K. Chin, and R. Gupta, "Wireless Wakeups Revisited: Energy Management for VoIP over Wi-Fi Smartphones," Proc. ACM MobiSys, Pp. 179-191, 2007.

[4] Y. Agarwal, C. Schurgers, and R. Gupta, "Dynamic Power Management Using on Demand Paging for Networked Embedded Systems," Proc. Asia South Pacific Design Automation Conf., Vol. 2, Pp. 755-759, 2005.

[5] P. Bahl, A. Adya, J. Padhye, and A. Wolman, "Reconsidering Wireless Systems with Multiple Radios," ACM SIGCOMM Computer Comm. Rev., Vol. 34, No. 5, Pp. 39-46, 2004.

[6] A. Chaman and S. Pierre, "On the Planning of Wireless Sensor Networks: Energy-Efficient Clustering under the Joint Routing and Coverage Constraint," IEEE Trans. Mobile Computing, Vol. 8, No. 8, Pp. 1077-1086, Aug. 2009.

[7] S.M. Kim, J.W. Chong, B.H. Jung, M.S. Kang, and D.K. Sung, "Energy Aware Communication Module Selection through ZigBee Paging for Ubiquitous Wearable Computers with Multiple Radio Interfaces," Proc. Int'l Symp. Wireless Pervasive Computing, Pp. 37- 41, 2007.

[8] T. Pering, Y. Agarwal, R. Gupta, and R. Want, "CoolSpots: Reducing the Power Consumption of Wireless Mobile Devices with Multiple Radio Interfaces," Proc. ACM MobiSys, Pp. 220-232, 2006.

[9] E. Shih, P. Bahl, and M.J. Sinclair, "Wake on Wireless: An Event Driven Energy Saving Strategy for Battery Operated Devices," Proc. ACM MobiCom, Pp. 160-171, 2002

[10] O. Younis and S. Fahmy, "HEED: A Hybrid, Energy-Efficient, Distributed Clustering Approach for Ad Hoc Sensor Networks," IEEE Trans. Mobile Computing, Vol. 3, No. 4, Pp. 366-379, Oct.-Dec. 2004.