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Energy Efficient Multi Hop Clustering Protocol for Wireless Networks

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Abstract- Bluetooth and wireless LAN communication models are used in mobile devices. Mobile devices are equipped with multi radio features for WLAN and Bluetooth communications. IEEE 802.11 standards are used for WLAN communication. Bluetooth supports bandwidth level of 2 Mbps with a range of 10 meters. Wireless LAN communication requires high energy resources. Wireless LAN communication model is integrated with Bluetooth communication mechanism. Bluetooth Personal Area Network (PAN) is formed with one cluster head and a set of nodes. Low power Bluetooth is used to access WLAN resources. Cooperative networking (CONET) protocol is used to dynamically cluster the nodes. Node's bandwidth requirement, energy use, and application type details are used in cluster construction process. Clustering is performed independently of WLAN access points. CONET protocol reduces the energy consumption in WLAN. CONET protocol supports single hop clustering model. Limited coverage and constraint based WLAN access are the main problems in CONET protocol. CONET protocol is enhanced with multi hop clustering model. Max-Min D-Clustering algorithm is integrated with CONET protocol. Cost functions are optimized to multi hop clustering. Coverage maximization is achieved with Bluetooth.

Index Terms- Polarization, Reflection guide map, Mask layers

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 degrading its performance.

About 70 percent of smart phones in the market have a Bluetooth interface as a secondary radio for personal area networking [2]. 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, 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 [1]. 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 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. 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 [8], data aggregation [7], or energy efficiency. In our work, clustering makes nodes that share their WLAN interfaces with each other. Depicts the concept of our approach and compares it to the previous approaches. 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. 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, while the previous approaches require specialized APs with dual radios. Moreover, we solved the scalability problem of the previous works. 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.

One unique requirement which distinguishes our approach from the traditional clustering problem in sensor networks is that, unlike sensor nodes which are left unattended after deployment, mobile devices 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

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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 networks by exploiting a secondary radio,
2. Dynamically configuring clusters to meet the bandwidth 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 computers 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 communication systems.

II. 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 [9] and MAC layer [5]. 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, 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 [4]. In contrast, CONET needs only a simple software patch at OS level, resulting fast deployment to existing mobile devices and infrastructures.

As mobile devices increasingly feature multiple radios, the idea of using a secondary low-power radio to reduce the power consumption of the WLAN interface. In [3], a VoIP device exploits a secondary radio as a wake-up channel, but this incurs long latencies for activating the sleeping device. For general applications, several paging schemes have been proposed, but they also contain the latency problem to activate the WLAN channel. CoolSpots and SwitchR use the secondary radio not only for control signaling but also for data communication. They alleviate the latency problem and save more energy by lengthening the power-off time of WLAN interfaces. However, they require hardware/software modifications of existing LAN environment for deployment. Conceptually, CoolSpots and SwitchR can be special cases of CONET: if a dual AP exists, it can be regarded as a stationary node whose cost is always zero (lowest) thus always acts as a cluster head.

III. PROBLEM STATEMENTS

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 properties 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. Each node can communicate with the access point using its WLAN interface, regardless of its location and time.

3. The WLAN access points do not have Bluetooth interfaces. This is typical for most existing wireless environments. Therefore, the previous approaches are inapplicable.

4. Each node i knows the total bandwidth required, Need BW_i, and the free bandwidth of its Bluetooth link, Free BW_{it}.

5. Each node i can measure its residual energy E_{it}.

6. All Bluetooth interfaces have the same communication 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.

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 C_j, the sum of bandwidth requirements of all regular nodes within the cluster must not exceed the maximum data rate of Bluetooth R_B, i.e., $\sum_{RNK\in}$.$NeedBWk_{(t)} \leq AR^B$, where RN_k is the regular node of ID k and $NeedBW_k(t)$ is the required bandwidth for node k at time t.

3. 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.

IV. THE CONET PROTOCOL

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

A. 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 a group networking scenario: nodes 1, 2, and 3 have a common collaborative task and attempt to maximize the group lifetime.

A.1 CLUSTER HEAD ADVERTISEMENT

When a node is newly booted up, it becomes a CH, as shown in the flow chart (Fig. 1). Assume that all three nodes of the example are booted up at the same time. Then, since all of them independently become CHs, three clusters are created. However, the only member of each cluster is the cluster head itself. Like these clusters, a cluster which has no RNs is called a trivial cluster, and the head of the trivial cluster is called a trivial cluster head (tCH). Therefore, tCHs do not need to use Bluetooth for packet forwarding, but only for advertising. Note that tCH is a subset of CH.

When a node becomes a CH, it starts to advertise its resource information periodically via 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 $FreeBW_i$, and some required information, such as the ID and the network address. Each node manages a set S_i^{CH}, which stores the information advertised by neighboring CHs.

Because act as gateways that connect Bluetooth nodes (RNs) to the WLAN access point, $FreeBW_i$ of CH i should be the smaller value between Free BW_i^w and $FreeBW_i^B$, the 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 [6].

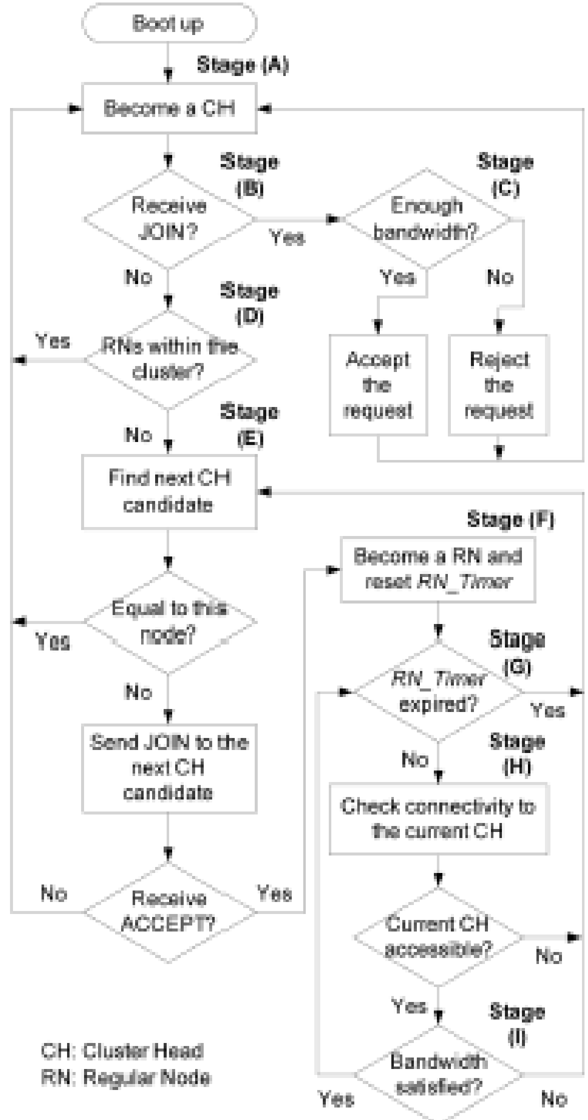


Fig. 1: Flow chart of CONET clustering protocol.

For example, we can estimate the free bandwidth using the idle channel time. 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 channels (T^{w_i} and $T^{\mathbf{B}_i}$, respectively) during a period of time T, each node i can estimate its Free BW_i^w and $FreeBW_i^B$ using a moving average with weight 2 =0, 1 as follows:

$$\text{Free } BW_i^w = \alpha \text{ Free } BW_i^w + (1-\alpha) \frac{T^{W_I}}{T} R^W - R^{mar}, (1)$$

$$\text{Free } BW_i^w = \alpha \text{ Free } BW_i^w + (1-\alpha) \frac{T^{B_I}}{T} R^{B -} R^{mar,}R, (2)$$

Where R^W and R^B are the transmission rates of WLAN and Bluetooth, respectively. R^{mar} 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 R^W is a predefined constant, but the IEEE 802.11 standard provides multiple transmission rates depending on Signalto 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 $FreeBW^B$. In summary, the free bandwidth of node i, $FreeBW_i$, can be obtained as follows:

$$FreeBw = \begin{cases} Min(\mathrm{Free\,BW_i^W}, \mathrm{FreeBW_i^B}), \\ \quad if\ \ node\ \ i\ \ is-a\ \ \ CH_i \\ \mathrm{FreeBW_i^B}, \qquad otherwise. \end{cases}, (3)$$

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

A.2 Responding To Joint Requests

In stage (B) of Fig. 1, each CH waits for JOIN requests from other nodes for a short time. The JOIN message of node i includes the amount of required bandwidth $NeedBW_i$. 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, 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, because no node has sent a JOIN message yet, all the nodes go down to stage (D).

A.3 Cluster Head Election

When there is no JOIN request, the CH counts the number of RNs within its clusters (stage (D) in Fig. 1). 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 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:

FIND_NEXT_CH:

1) Prune the node which has insufficient bandwidth. Let Si^{CH} and Si^{CH} be the original and pruned neighboring CH set of node I, For each node $K \in Si^{CH}$,if MIN (Free BW_i ,Free BW_K) $\geq$ Need BWi, then copy K into S^iCH

2) Find i's next CH candidate which has the lowest cost among I and all nodes in Si^{CH}

3) Return the Selected node.

Even though all nodes estimate FreeBW using (3), the estimation results of two neighboring nodes could be different due to the limited radio range. For example, let us assume that there is a hidden flow on the left side of node 1, 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 $FreeBW^1$. This indicates that the free bandwidth on the link between nodes i and k should be the minimum value between $FreeBW_i$ and $FreeBW_k$, i.e., MIN($FreeBW_i$,$FreeBW_k$) 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 S_1^{CH} setCHSet S_1^{CH} .

Next, node 1 selects the lowest cost node among the nodes in S_1^{CH} and itself. For simple explanation, let us assume that the cost of each node i, C_i, is simply the reciprocal of its residual energy Ei, i.e., $C^i = 1/E_i$. 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, 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.

B. Application Types and Cost Functions

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

B.1 Group Networking

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, e.g., (maximum energy)/(residual energy). This cost function distributes energy dissipation over the network particularly well when the power consumption rates are equal for all nodes. In CONET, however, a variety of nodes types made by 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, Cit, as follows:

$$C_i(t) = \frac{1}{L_i(t)} \ldots\ldots\ldots\ldots\ldots(4)$$

Where $\tilde{L}t_i$ is node i's estimated lifetime. We assume that each node i knows its current power consumption $P_i(t)$ and residual energy $E_i(t)$. Then, the lifetime estimation is based on the moving average of the current and past power usage.

B.2 Individual Networking

For individual networking, energy saving should be as equal as possible to all cooperating nodes. This motivates us to use the energy saving ratio (ESR) as the cost for individual networking. Our goal is to equalize ESR among all cooperating nodes. Consider node i, which was booted up at t = 0 and has cooperated with others using CONET for [0, t] t >0. The role (CH or RN) of the node and cluster organization may have changed with time, depending on its resource usage. Using the cumulative amount of energy consumption, the energy saving ratio of node i at time t, $ESR_i(t)$, can be defined as follows:

where Pit represents the future power consumption estimated at time t. Once Pit has been estimated, the node can calculate its Lit as follows:

$$ESR_i(t) = \frac{\overline{E}_i^{tr}(t) - \overline{E}_i^{co}(t)}{\overline{E}_i^{tr}(t)} = 1 - \frac{\overline{E}_i^{co}(t)}{\overline{E}_i^{tr}(t)}, \quad (5)$$

Where $\overline{E}_i^{tr}(t)$ represents the expected energy that would be consumed if node i had communicated in the traditional WLAN-only manner (i.e., without CONET) during I =0; t $\overline{E}_i^{co}(t)$ represents the energy actually consumed by the node when it has used CONET. Therefore, $\overline{E}_i^{co}(t)$ mainly depends on the history of the node's current and past roles: when the node is an RN, $\overline{E}_i^{co}(t)$ will increase more slowly than $\overline{E}_i^{tr}(t)$ because RNs use only Bluetooth, resulting in an increase in ESR_{it}. Otherwise, when the node is a CH, $\overline{E}_i^{co}(t)$ will increase as fast as (or slightly faster than) $\overline{E}_i^{tr}(t)$ thus, ESR_{it} will decrease. According to (5), high ESR means that by cooperating with others, the node could save more energy than the others. Therefore, every time nodes rotate their roles, CONET selects high-ESR nodes as the next CHs, allowing low-ESR nodes to become RNs for energy saving. We define the cost of being a CH for node i at time t, Cit, as follows:

$$C_i(t) = 1 - ESR_i(t) = \frac{E_i^{co}(t)}{\tilde{E}_i^{tr}(t)} \quad (6)$$

With appropriate role switching periods, our protocol equalizes ESR among nodes.

V. CONET Protocol with Multi Hop Clustering Model

CONET protocol is enhanced with multi hop clustering model. Max-Min D-Clustering algorithm is integrated with CONET protocol. Cost functions are optimized to multi hop clustering. Coverage maximization is achieved with Bluetooth. The system is designed to improve data communication under the wireless LAN environment with energy management. The private area networks are formed to manage data transmission using Bluetooth. The clustering techniques are used for the PAN construction process. The system is divided into five modules. They are Network analysis, Single hop clustering, Multi hop clustering, PAN management and Data communication.

The network analysis module is designed to discover the nodes and their neighbors. The node grouping is performed under the single hop clustering process. Multi hop clustering module is designed to cluster the nodes with multi hop model. PAN construction module is designed to group up the bluetooth nodes. Data communication module handles the communication between the wireless nodes.

A. Network Analysis

The network analysis is performed to detect the node and network status. The WLAN nodes are connected through the access points. Nodes and their neighborhood nodes are identified in the network analysis. Nodes radio and energy details are collected in the network analysis.

B. Single Hop Clustering

Clustering process is carried out to manage energy and network load. CONET protocol is used for the clustering process. The bandwidth requirements are managed by the clusters. The clusters are configured dynamically.

C. Multi Hop Clustering

Max-Min D-Clustering algorithm is used for the multi hop clustering process. The CONET protocol is enhanced to support multi hop clustering process. The PAN construction is also tuned for multi hop clustering environment. Cluster head selection is optimized for multi hop clustering model.

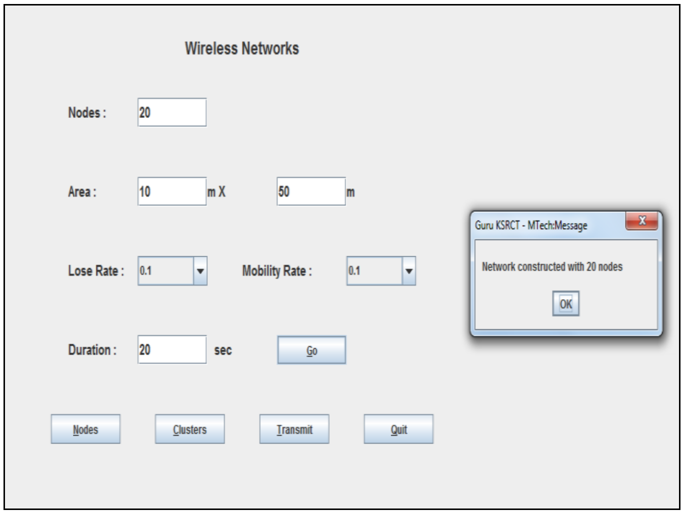
D. PAN Management

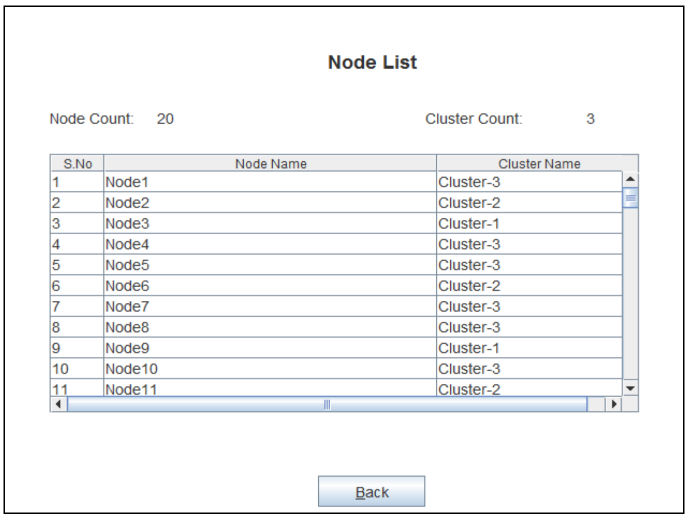
The private area network is constructed with Bluetooth enabled nodes. Cluster head (CH) manages the nodes under PAN. Regular nodes (RN) communicate with cluster head (CH). Cluster head is connected with wireless LAN access points.

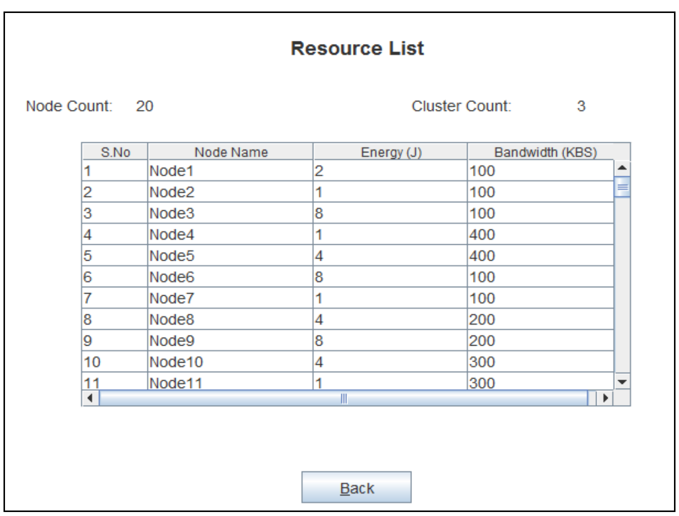
E. Data Communication

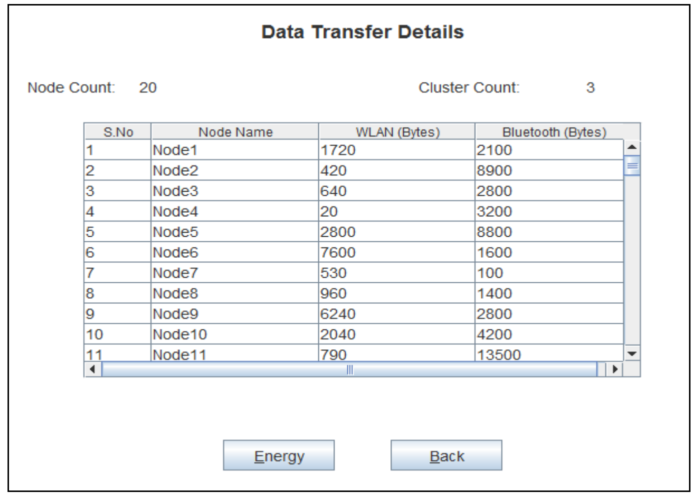
Data communication is done with WLAN and Bluetooth protocols. Secondary radio based communication is used to achieve energy efficiency. Cluster head manages the data transmission within its area. Cluster level transmissions are done through PAN nodes.

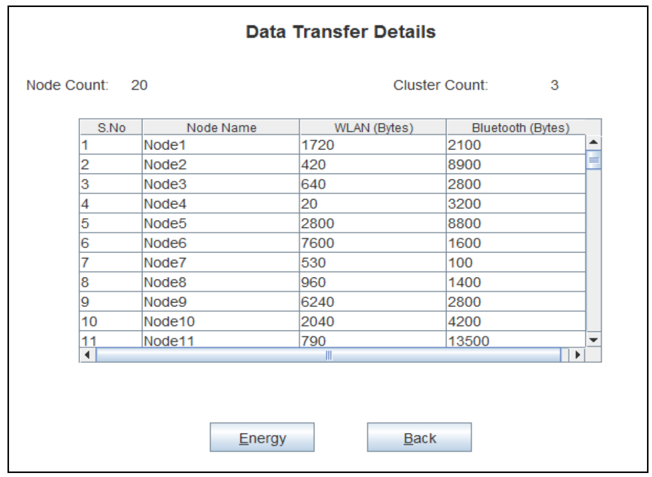
VI. SCREENSHOTS











VII. CONCLUSION

Wireless communication standards are used in Wireless Local Area Networks (WLAN). Clustering techniques are used to group up the mobile devices with Bluetooth communication. Cluster head manages the communication between the WLAN and bluetooth environment. CONET is a bandwidth aware and energy-efficient clustering protocol for multiracial 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.

Multi hop clustering scheme is used to handle data communication process. The system supports high frequency and low frequency environment. Multi hop is constructed. Cluster head manages the data transmission process. The system reduces the energy consumption.

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