

Smart WLAN Discovery for Power Saving of Dual-Mode Terminals

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Dual-mode terminals (DMTs) equipped with cellular and WLAN interfaces have become popular in recent years. Users of DMTs can enjoy high-speed WLAN Internet access and wide area Internet access to cellular networks. However, a DMT may consume power inefficiently when discovering a WLAN with inherently limited service coverage. In this letter, we propose to use smart WLAN discovery (SWD) to minimize the power consumption required for WLAN discovery. To minimize the power consumption of a DMT, an SWD DMT activates its WLAN interface only when the DMT transfers data within the WLAN coverage area. The simulation results of SWD show an improved power-saving performance compared to previous WLAN discovery schemes.

Keywords: WLAN, cellular network, smart WLAN discovery, enhanced WLAN access point, power saving.

I. Introduction

Dual-mode terminals (DMTs), which can connect to a WLAN and a cellular network, have recently grown in popularity. Users of a DMT can enjoy cellular communications (for example, voice calls and short message service) and Internet access within a wide area through a cellular network. Users can also enjoy high-speed Internet access through a WLAN if their DMT discovers an available WLAN. For cellular communication services, the DMT should always maintain connection to the cellular network. On the other hand, for high-speed Internet access, WLAN discovery is important

because a WLAN has limited service coverage. If a DMT is located outside of the WLAN coverage and keeps its WLAN interface turned on to discover a WLAN, it consumes redundant power for WLAN discovery.

To reduce the power consumption of the DMT, two types of WLAN discovery schemes have been studied [1]-[3]. One type of scheme (Type A) was proposed for a DMT to wake up its WLAN interface periodically on its own to discover a WLAN [1]. If a Type A DMT discovers a WLAN and there is data to be transferred between the DMT and the network, the data will be transferred through the WLAN. If the WLAN is discovered during the data transfer over a DMT's cellular interface, the DMT performs a handover from a cellular network to a WLAN and transfers data through the WLAN.

The other type of scheme (Type B) was proposed for a DMT to wake up its WLAN interface for WLAN discovery on its own or by receiving control signals (for example, a paging signal) from a cellular network just before the data transfer [2], [3]. If a Type B DMT does not transfer data through a WLAN, it turns off its WLAN interface. When a Type B DMT has data to be sent, it activates its WLAN interface on its own. If there is data to be delivered to the Type B DMT, a cellular network sends control signals to the DMT to activate the DMT's WLAN interface. If a Type B DMT with an activated WLAN interface can find a WLAN, it transfers data through a WLAN. Otherwise, it transfers data through a cellular network and turns its WLAN interface off.

A Type B DMT consumes less power for WLAN discovery than a Type A DMT because the Type B DMT tries to discover a WLAN only just before the data transfer. However, the Type B DMT may cause inefficient power consumption, depending on its movement. When the DMT transferring data through a WLAN moves out of the WLAN coverage, as shown in Fig. 1(a), the Type B DMT can detect the decreasing WLAN

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signal strength and perform a handover to a cellular network. On the other hand, as shown in Fig. 1(b), when the DMT transferring data through a cellular network moves into WLAN coverage, the Type B DMT cannot connect to the WLAN because its WLAN interface was already turned off when it was outside the WLAN coverage area. In this case, the Type B DMT consumes power inefficiently since the cellular interface is less power-efficient than the WLAN interface for a data transfer [4]. If the Type B DMT with a deactivated WLAN interface can discover a WLAN, its power efficiency will increase.

In this letter, we propose smart WLAN discovery (SWD) as an enhanced Type B scheme. An SWD DMT wakes up its WLAN interface on its own or by receiving the control signals from a cellular network, as in the Type B DMT. However, the SWD DMT can discover a WLAN even though it moves into the WLAN coverage area with its WLAN interface turned off. SWD can be achieved by means of an integrated WLAN/cellular network architecture.

The remainder of this letter is organized as follows. Section II presents our proposed SWD for integrated WLAN/cellular networks. To evaluate performances of WLAN discovery schemes, we conduct a simulation after modeling the power consumption and mobility of a DMT. Sections III and IV describe a power consumption model and a mobility model for simulation, respectively. Section IV also explains simulated

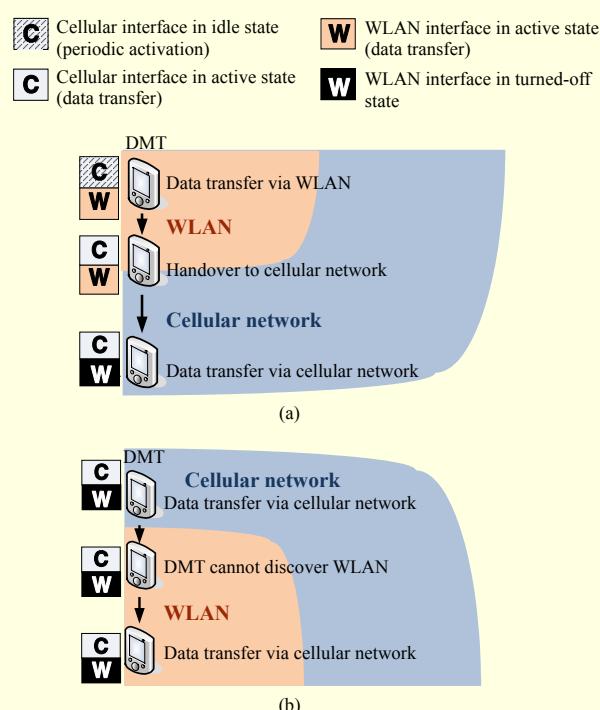


Fig. 1. Operation of Type B DMT depending on its movement:
(a) moving out of and (b) into WLAN coverage.

power consumption results for the preexisting and the proposed WLAN discovery schemes. Finally, section V offers some concluding remarks regarding our proposal.

II. Smart WLAN Discovery in Integrated WLAN/Cellular Networks

SWD is derived from our previous work [5] for an integrated WLAN/cellular network [6]. SWD function operates in an integrated WLAN/cellular network consisting of a smart-WLAN access point (S-WAP) and a smart PDN gateway (P-GW), as shown in Fig. 2. The S-WAP is an enhanced WLAN access point (AP) and can listen to cellular uplink signals. The smart P-GW is an enhanced P-GW of a cellular network and can activate the DMT's WLAN interface by sending control signals.

Figure 2 shows the procedure of SWD. The SWD DMT turns off its WLAN interface when it is out of WLAN coverage. When a DMT moves into WLAN coverage of an S-WAP, the S-WAP can listen to cellular uplink signals from the DMT. The S-WAP measures the strength of the cellular uplink signal (①). The S-WAP sends the measured data of the cellular uplink signal strength, the DMT's identifier (for example, the DMT's media access control address), and the WLAN configuration information (for example, the service set identifier, channel assignment, and security parameters) to the smart P-GW through a secured tunnel between the S-WAP and the smart P-GW (②). The smart P-GW selects the S-WAP that reported the highest signal strength of the DMT's cellular uplink and sends the S-WAP's WLAN configuration information to the DMT through the control signals of the cellular network (③). The DMT can connect to the WLAN with this information and transfer data through the WLAN (④).

The S-WAP function can be incorporated in an integrated femtocell access point (FAP), which integrates a cellular FAP and a WLAN AP. Integrated FAPs have been produced by Motorola, Huawei, NEC, SK Telecom, and KT to save the deployment costs of a cellular FAP and WLAN AP. Using an integrated FAP, the S-WAP function can be implemented

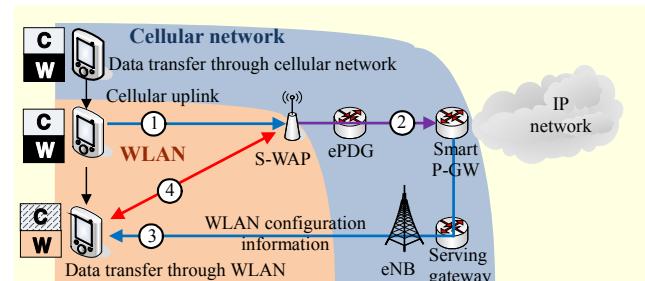


Fig. 2. Procedure of SWD in integrated WLAN/cellular networks.

without a significant amount of additional cost.

III. Power Consumption Model for WLAN Discovery Schemes

The communication state of the DMT can be one of the following.

- State I: The DMT does not send or receive data.
- State Ca: The DMT sends or receives data through a cellular network.
- State Wa: The DMT sends or receives data through a WLAN.

The power consumption of the DMT, P_{DMT} , can be modeled as

$$P_{\text{DMT}} = \pi_I P_I + \pi_{\text{Ca}} P_{\text{Ca}} + \pi_{\text{Wa}} P_{\text{Wa}}, \quad (1)$$

where π_I , π_{Ca} , and π_{Wa} are the probabilities of States I, Ca, and Wa, respectively. These can be expressed as $\pi_I=1-\lambda/\mu$, $\pi_{\text{Ca}}=(1-U)\lambda/\mu$, and $\pi_{\text{Wa}}=U\lambda/\mu$ using the call arrival rate (λ), call service rate (μ), and WLAN usage ratio (U). The WLAN usage ratio is the average ratio of the data transfer duration through a WLAN to the total data transfer duration, as given in [5].

P_I , P_{Ca} , and P_{Wa} represent the power consumption of the DMT in States I, Ca, and Wa, respectively. We assume that the power consumption of the DMT is the sum of the power consumed by the WLAN and cellular interfaces. We also assume that P_{CI} is the power consumption of the cellular interface for periodic activation (idle state of a cellular interface) and P_{CA} is the power consumption of the data transfer (active state). Similarly, P_{WP} and P_{WA} represent the power consumption of the WLAN interface for periodic activation (power save mode [PSM] of a WLAN interface) and for the data transfer (active state), respectively.

Using these values, P_I , P_{Ca} , and P_{Wa} of the Type A DMT are expressed as $P_I=P_{CI}+P_{WP}$, $P_{\text{Ca}}=P_{CA}+P_{WP}$, and $P_{\text{Wa}}=P_{CI}+P_{WA}$, respectively, because the Type A DMT's WLAN interface enters PSM when the DMT's WLAN interface does not transfer data. For the Type B and SWD DMTs, P_I , P_{Ca} , and P_{Wa} are expressed as $P_I=P_{CI}$, $P_{\text{Ca}}=P_{CA}$, and $P_{\text{Wa}}=P_{CI}+P_{WA}$, respectively, because the Type B and SWD DMTs turn off the WLAN interface unless the DMT transfers data through a WLAN.

For non-real-time traffic (for example, file transfer protocol traffic), μ is determined by U , the data size (D), the WLAN data rate (R_W), and the cellular data rate (R_C) as follows:

$$\mu = \frac{R_W U + R_C (1-U)}{D}. \quad (2)$$

R_W is usually larger than R_C . The power consumption for a data transfer (P_{Ca} and P_{Wa}) is larger than the power consumption when there is no data transfer (P_I). Hence, from (1) and (2), the relationship between U and P_{DMT} can be derived as follows:

$$P_{\text{DMT}} \propto 1/U. \quad (3)$$

When the DMT moves into WLAN coverage, the Type B DMT fails to discover a WLAN, as shown in Fig. 1(b), but the SWD DMT can discover a WLAN, as shown in Fig. 2. Therefore, we can expect that the SWD DMT has a larger WLAN usage ratio than the Type B DMT, and the SWD DMT consumes less power than the Type B DMT.

IV. Simulated Power Consumption Results

This section shows the simulated power consumption results of WLAN discovery schemes. For the simulation, we use the mobility model shown in Fig. 3. As shown in Fig. 3(a), we assume that the cellular area comprises multiple segments and that all segments have equal size in regular hexagonal shape (radius=50 m). The segments of the WLAN area are uniformly distributed with the probability of WLAN coverage ratio (β), which is the ratio of total WLAN coverage areas within a cellular cell to that of the cellular cell. Segments other than WLAN areas can be covered by only cellular networks with $1-\beta$ probability. Thus, when the DMT moves to an adjacent segment, β is the probability that the adjacent segment is covered by a WLAN; $1-\beta$ is the probability that the adjacent segment is covered by only a cellular network. Thus, the state transition of the mobility model can be described as shown in Fig. 3(b). The segment residence time (T), during which the DMT remains at a segment, has a gamma distribution [7]. For a given T , the maximum moving speed (V) of the DMT crosscutting a segment is calculated as

$$V = \text{Diameter of a hexagonal segment} / T. \quad (4)$$

We simulate the power consumption of the DMT using the MATLAB tool, the power consumption model presented in section III, and the mobility model shown in Fig. 3. D and λ of the non-real-time traffic are assumed to have a Pareto distribution with an average of 150 MB and an exponential distribution with an average of 1 per hour, respectively. R_C and R_W are 2 Mbps and 20 Mbps, respectively, and P_{CI} , P_{CA} , P_{WP} , and P_{WA} are 13 mW, 850 mW, 130 mW, and 1,000 mW, respectively [4]. We conduct a simulation using three mobility scenarios with different mean and standard deviation of T . The mean and standard deviation of T for Mob 1 ($V=100$ m/h) are 60 min and 60 s, those for Mob 2 ($V=600$ m/h) are 10 min and 10 s, and those for Mob 3 ($V=6$ km/h) are 1 min and 1 s, respectively. The total simulation time for each mobility scenario is 1,000,000 min.

Figure 4(a) shows the power consumption results for the WLAN discovery schemes. Regardless of the mobility scenario and WLAN coverage ratio, the Type A DMT

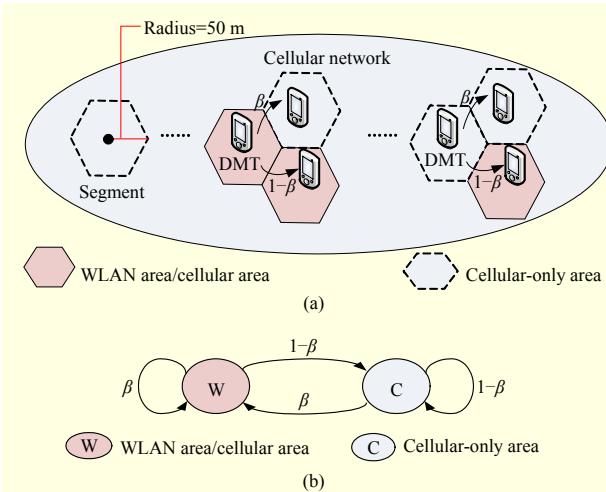


Fig. 3. Mobility model for power consumption simulation: (a) using segmented regions and (b) state transition.

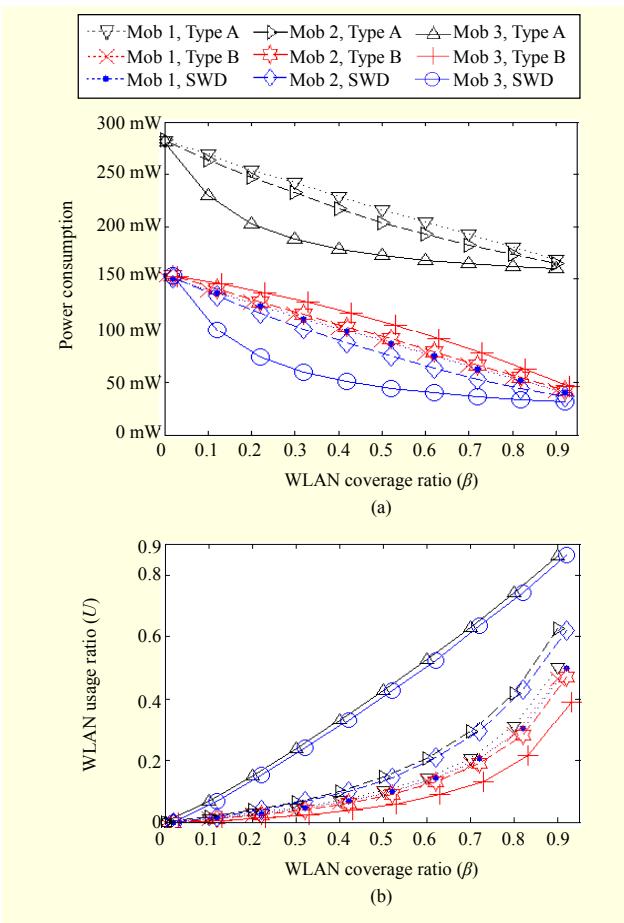


Fig. 4. (a) Power consumption and (b) WLAN usage ratio.

consumes the most power, and the SWD DMT the least; the power consumption of the Type B DMT is between that of the Type A DMT and that of the SWD DMT. The highest power consumption of the Type A DMT is mainly caused by the

power consumption in State I and State Ca, which is higher than that of any other type of DMT, as implied in (1). As shown in Figs. 4(a) and 4(b), Type A and SWD DMTs consume less power and have a larger WLAN usage ratio at high mobility (Mob 3) than at low mobility (Mob 1 and Mob 2). However, the Type B DMT consumes higher power and has a smaller WLAN usage ratio at high mobility (Mob 3) than at low mobility (Mob 1 and Mob 2). The Type B DMT has difficulty discovering WLANs after moving out of a WLAN segment. The simulation results are consistent with (3), which shows the relationship between the power consumption and WLAN usage ratio of the DMT.

V. Conclusion

We proposed the use of smart WLAN discovery (SWD) for the power saving of dual-mode terminals (DMTs). An SWD DMT saves power by turning on the DMT's WLAN interface only when there is data to be transferred within WLAN coverage. To activate the DMT's WLAN interface, an enhanced WLAN AP and the control signals of the cellular network are used. Our simulation results show that SWD outperforms the previous WLAN discovery schemes in terms of power consumption. While SWD improves the power saving performance, SWD requires network complexity owing to the use of the S-WAP and smart P-GW. Future work will be conducted to reduce the network complexity for SWD.

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