A Power Saving Scheme for Integrated WLAN and Cellular Networks*

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Abstract. For the integration of WLAN and cellular networks, there have been recently several efforts to provide an optimized system design. However, it is noted from the existing schemes that in idle state, WLAN interface is supposed to be periodically turned on to receive periodic beacons from access points with cellular interface turned on at the same time for the paging from base station, resulting in significant power consumption. Therefore, in order to save the power consumption, when WLAN interface goes to idle state, we propose to turn off the WLAN interface without any periodic wake-up while at the same time, the existing paging of cellular networks are utilized. It is confirmed via both analytical modeling and simulation that the proposed scheme achieves better performance as compared to techniques currently adopted in WLAN in terms of power consumption.

1 Introduction

Most recently, a significant number of carriers are migrating towards heterogeneous wireless networking where Wireless Local Area Networks (WLANs) based on IEEE 802.11 standards and 3G (third-generation) cellular networks co-exist, in order to offer Internet access to end users with better Quality of Service (QoS). However, cost-effective integration of heterogeneous wireless networks is not yet accomplished, so that there have been many research activities having focused on this integration [1]-[3].

It is a challenge to maintain mobile terminals' active connections as they move across over different types of wireless networks (that is known as "vertical handoff"), while minimizing power consumption [1]. There have been several efforts to connect mobile device equipped with multiple interfaces, to the most optimal one among the access networks in terms of network performance. In [1], new performance metrics are introduced for providing seamless mobility. The authors of [2] proposed an end-to-end mobility management system that reduces ping-pong effect by obtaining the condition of different networks. Various network layer based inter-network handover techniques are addressed and their performance is investigated in [3].

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Here, it is worthy of notice that a large portion of the power consumption in wireless interface is idle power. In most of the existing vertical handoff management schemes [1]-[3], MN (Mobile Node) must turn on both WLAN and cellular interfaces at once even in the idle state with power save mode to receive periodic beacons from Access Points (APs) while receiving paging messages from Base Station (BS), resulting in significant power consumption.

Therefore, in this paper, in order to save power consumption of MN in the integrated WLAN and cellular networks, when WLAN interface goes to idle state, we propose to turn off the WLAN interface without any periodic wake-up while at the same time, the existing Paging Channel (PCH) of cellular networks is utilized to turn on the WLAN interface for incoming data. Noting that WLAN is primarily used for accessing Internet where mainly downloading relatively long-lived multimedia data service and the WLAN interface is forced to be in the idle state for most of the time, it is beneficial to turn off WLAN interface for the idle period.

It is confirmed via both analytical modeling and simulation results that the proposed power saving scheme achieves better performance as compared to techniques currently adopted in WLAN in terms of the total power consumption.

2 Power-Efficient Interface Switching

When connected to a WLAN, WLAN interface card is usually in idle mode for around 70% of the overall time [4]. In idle state, the power consumption level for WLAN interface is about 10 times as great as that of cellular interface [5]. Our scheme targets on saving this power consumption, where WLAN interface is turned off without any periodic wake-up during idle period, which is called "inactive" state in this paper. Herein, WLAN interface has following states:

– Communication state: WLAN interface sends or/and receives data.
– Non-communication state: WLAN interface goes to this state when the data session completes.
  1. Typical WLAN: Idle state; 2. Proposed system: Inactive state

In our system model, in idle state, the cellular interface is assumed to listen continuously to the PCH to detect messages directed at APs in its cell as well as itself. The PCH of cellular network is utilized also to provide the information about APs in its current cell– Serving GPRS Support Node (SGSN) has an acquisition of IP address and Service Set Identifier (SSID) of all APs in its coverage where some 802.11 gateways serving the APs have a direct link to the SGSN, at the stage of configuration where BSs are initialized.

In this paper, we focus on downlink traffic since it is envisioned that 4th generation wireless system's traffic pattern will be highly asymmetrical, with 50/1 ratio or more favoring the downlink. Basing our system on 3GPP system, note that Radio Network Controller (RNC) is responsible for controlling user connections between a user and the core network with buffers for different users [6]. Thus, for downlink transmission, BS notifies MN when the number of packets

Table 1. Detailed procedure of the proposed power saving scheme for downlink traffic for integrated WLAN and cellular networks

(1) For downlink transmission, data traffic comes into a per-user-buffer at RNC when MN's WLAN interface is in inactive state. **(2)** Once the number of packets in the buffer reaches to threshold n, the BS notifies the MN about the existence of downlink data via its PCH. **(3)** On receiving the notification, WLAN interface is turned on (i.e. goes to communication state) and WLAN_IF_READY message is sent to corresponding 802.11 gateway while receiving the incoming data through cellular network. **(4)** Upon receiving the WLAN_IF_READY message, the 802.11 gateway sends VERTICAL_HANDOFF_COMPLETE message including the SSID and MAC address of the AP selected for the MN. **(5)** Once the SGSN receives the VERTICAL_HANDOFF_COMPLETE message, it starts to forward the remaining data to 802.11 gateway instead of to the BS. **(6)** The 802.11 gateway transmits the remaining data received from the SGSN to the MN.

in a per-user-buffer at RNC [6] for incoming data reaches a certain threshold n (usually, $\leq$ maximum buffer size) so that the MN should not consume its power due to frequent turn-on and off actions which might occur if MN should be awakened upon receiving a packet from cellular network. The proposed power saving scheme for downlink traffic is described at length in Table 1.

3 Analytical Model of Power Consumption

Typically, users' packets are separated into buffers at RNC [6] while BS simultaneously serves a number of users so that BS should provide the opportunity for a scheduler to select the optimal user to transmit to at any instant [7]. To investigate the performance of the proposed scheme, we now develop an analytical model for heterogeneous networks treating the per-user-buffer at RNC with the traffic common in WLAN system, also considering the power on/off state of WLAN interface.

Unlike a cellular network, as far as traffic patterns are concerned, WLAN system is characterized as its traffic has an on/off behavior [8]. For example, for a web page transfer, a MN alternates between on period, t_{on} and off period, t_{off} during which a set of web pages is used to be downloaded as an application session and there is no traffic due to user's thinking time, respectively. The probabilities of a MN being in t_{on} and of a MN being in t_{off} are given by $p_{t_{\text{on}}} = \frac{\alpha}{\alpha+\beta}$ and $p_{t_{\text{off}}} = \frac{\beta}{\alpha+\beta}$, respectively. Both on and off periods are assumed to have an exponential distribution with the mean, β^{-1} and α^{-1}, respectively. During t_{on} period, we assume that traffic arrives with a Poisson distribution the mean of which is λ. It is also assumed that each mobile user has only one TCP session active at a time from cellular network due to the lack of multi-tasking ability in current operating system of mobile device for cellular networks.

Let N be the maximum number of packets allowed in a per-user-buffer at RNC. If we set the threshold n to the buffer size, N, the arrival process to each

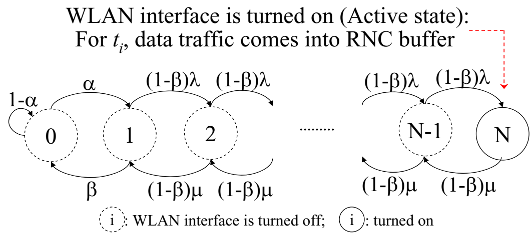

Fig. 1. State transition diagram for $n = N$

buffer of RNC can be modeled as an Interrupted Bernoulli Process (IBP). In the first place, to analyze the buffer under our proposed scheme with $n = N$, we note that during t_{off} period, the buffer content must be zero. When the state of the buffer at RNC first makes a transition to t_{on} state, for each subsequent transition to the same t_{on} state, a packet arrives to the buffer with mean λ while at the same time, the content of the buffer is transmitted to the MN through cellular interface with mean rate μ until the BS wakes up the corresponding WLAN interface by its PCH or the traffic flow ends without turning on WLAN interface due to the transient characteristic of the current traffic. Therefore, we are able to construct a Markov chain model for per-user-buffer at RNC as shown in Fig 1. If we denote p_i as the steady-state probability that the buffer contains i packets, then the steady-state probabilities are given by

$$p_0 = p_{t_{\text{off}}} \tag{1}$$

$$\alpha p_0 = \beta p_1 \tag{2}$$

$$\alpha p_0 + (1-\beta)\mu p_2 = (1-\beta)\lambda p_1 + \beta p_1 \tag{3}$$

$$\lambda p_{i-1} + \mu p_{i+1} = (\lambda + \mu) p_i \qquad 2 \le i \le N-2 \tag{4}$$

Let x and t_i denote the time elapsed from the moment when the WLAN interface is turned on and the time taken to initialize WLAN, respectively. Since $p_0 = \frac{\beta}{\alpha+\beta}$, from Eqs. 1-4, the rate at which WLAN interface is turned on from inactive state is given by

$$\begin{aligned} p_{on}^{(N)} &= (1-\beta)\lambda p_{N-1}(1-(1-\beta)\mu p_N)u(x) \\ &= \frac{\alpha(1-\beta)\lambda\rho^{N-2}}{\alpha+\beta}\left(1 - \frac{\alpha(1-\beta)\lambda\rho^{N-2}}{\alpha+\beta}\right)u(x) \end{aligned} \tag{5}$$

where $u(x) = \begin{cases} 1 & t_i - x > 0 \\ 0 & t_i - x \le 0 \end{cases}$ and $\rho = \frac{\lambda}{\mu}$. Thus, it can be easily known from the case of $n = N$ that the rate at which WLAN interface is turned on with $n = k$ becomes $p_{on}^{(k)} = (1-\beta)\lambda p_{k-1}(1-(1-\beta)\mu p_k)u(x) = \frac{\alpha(1-\beta)\lambda\rho^{k-2}}{\alpha+\beta}(1 - \frac{\alpha(1-\beta)\lambda\rho^{k-2}}{\alpha+\beta})u(x)$.

For the proposed scheme with $n = 1$ where WLAN interface is turned on from inactive state once the first packet of traffic flow comes to the buffer at RNC, the rate at which WLAN interface is turned on from inactive state is expressed as

$$p_{on}^{(1)} = \alpha p_0 = \frac{\alpha\beta}{\alpha+\beta}. \tag{6}$$

For the case of typical WLAN interface with power save mode, the sleeping interface must wake up periodically to receive regular beacons coming from the AP, which identify whether idle interface has data buffered at the AP and waiting for delivery. For idle mode, let w and s denote the wake-up rate for receiving beacons from AP and the sleep rate after receiving beacons from AP, respectively, both of which are fixed. Then, for idle state with power save mode, we have the rate at which WLAN interface is turned on as followings:

$$\begin{aligned} p'_{on} =& (\alpha + (1-\alpha)\frac{w}{w+s})p_0 \\ =& \frac{(w+s\alpha)\beta}{(w+s)(\alpha+\beta)}. \end{aligned} \tag{7}$$

Now we can compute the average power consumed for non-communication state during unit time t. Let C_i and C_d be the power consumed for wake-up to receive beacon/data and the baseline power consumption for doze state of idle period, respectively. Let C_{ia} be the power consumption due to the wake up from inactive state to receive incoming data which will be vertically handed off from cellular network. For our proposed scheme, there is no baseline power consumption since MN goes to inactive state in non-communication state. Then, for non-communication state, the average power-consumption during time t is

$$PW_{nc} = \begin{cases} (C_i P'_{on} + C_d p_0)t & \text{for typical WLAN} \\ C_{ia} P_{on}^{(k)} t & \text{for PCP with } n = k \end{cases} \tag{8}$$

where in general, C_{ia} is known to be greater than C_i, so that C_i and C_{ia} are set to 0.68 W and 1 W, respectively while C_d is assumed to have the value of 0.06 W in this study, where the power consumption values are obtained from [5].

4 Performance Evaluation

To obtain some simulation results as well as numerical results, we assume that during on period, the downlink transmission rate to MN is 80 Kbps while t_{on} is 120 and 360 sec. It is also assumed that t_i is 1 sec. The buffer size, L_b and the packet size are set to is 20 Kbytes and 1000 bytes, respectively. For typical WLAN interface with power save mode, beacon period is set to 100 ms.

In Figs. 2 (a) and (b), the average power consumed by WLAN interface for non-communication state, PW_{nc} is plotted as a function of off period ranging from 30 to 360 sec for t_{on}=120 and 360 sec, respectively when R=50 Kbps which denotes the data rate to BS during t_{on}. The graphs in Fig. 2 show that PW_{nc} obtained with typical WLAN system is higher than the proposed system, where when $n = N$, the power consumption under the proposed scheme is lower than when $n = 1$ over all the ranges of off period. We also know that in terms of power consumption, the above observed performance improvement is valid, irrespective of whether the active period is 120 sec or 360 sec.

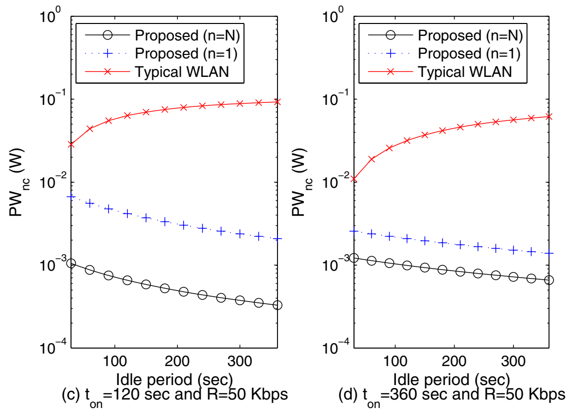

Fig. 2. Numerical power consumption versus off period

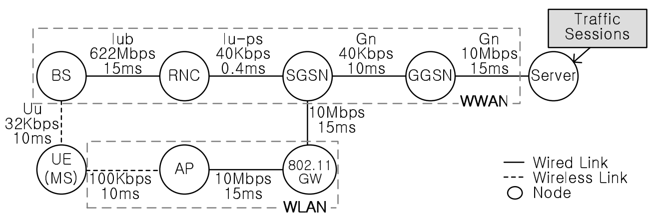

Fig. 3. Network topology

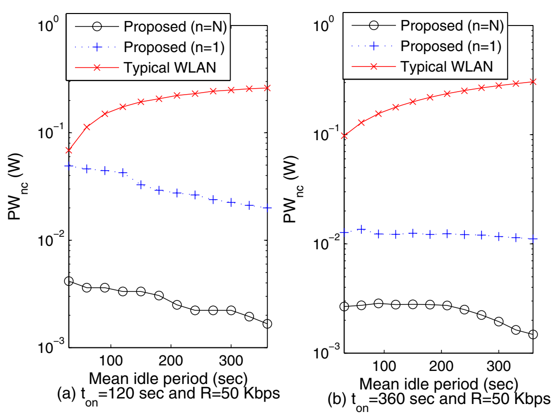

Fig. 4. Simulated power consumption versus varying mean idle period

Through simulation, we also compare the performance of the proposed scheme with typical WLAN system with periodic wake-up in idle state, in terms of power consumption for non-communication state. For this comparison, a simulation environment is created by extending the UMTS Terrestrial Radio Access Network (UTRAN) support modules [9]. The simulation topology is depicted in Fig. 3.

Fig. 4 plots the power consumed by the WLAN interface for non-communication state versus idle period ranging from 30 to 360 sec for R=50 Kbps when t_{on} is 120 and 360 sec. We observe that the power consumption behavior patterns shown in Fig. 4 are aligned along with the numerical results in Fig. 2. From the graphs in Fig. 4, it is also observed that the proposed scheme with $n = N$ works better with regard to power consumption, compared to that with $n = 1$ when the active period is smaller.

5 Conclusion

In this paper, we propose a power saving scheme for integrated WLAN and cellular networks, that utilizes the existing paging of cellular networks in order to turn off the WLAN interface during idle time. We aimed to save the power consumption resulting from periodic wake-up during the idle time.

Performance results for the proposed system are derived from the analysis as well as the simulation with regard to power consumption. The numerical and simulation results show that the power consumed in non-communication state for our scheme is lower than typical WLAN system because for the idle time, the power consumption resulting from the periodic wake-up is removed.

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