Reducing Power Consumption of IEEE802.11 Stations in Flexible Multicast Services

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ABSTRACT

Wireless LAN multicast can provide high quality location-aware content service. However, our research revealed that multicast might cause a significant increase in the power consumption. Flexible Multicast Service (FMS) which is defined in the IEEE 802.11v enables power efficient multicast service. In this paper, we prove that the FMS strategy is not optimal and a little extension on FMS will achieve great improvement in power efficiency without throughput or delay penalties.

Categories and Subject Descriptors

C.2.1 [Computer-Communication Networks]: Network Architecture and Design—Wireless communication

Keywords

Wireless LAN, Power Saving, Multimedia Streaming

1. INTRODUCTION

Wireless LAN multicast is an efficient tool to provide location-aware content broadcast services. For instance, exhibition organizers provide video, map and music at the exhibition venue. However, in most cases, these contents are provided through unicast, meaning that quality of contents is sacrificed because of a bandwidth limitation as the number of user increases. In such a case, multicast has a large advantage in distributing high quality content streams simultaneously. However, Wireless LAN multicast has two big well known problems. First, the IEEE 802.11 standard does not define a retransmission mechanism in multicast[2]. Second, the standard limits the available data rate in multicast. Many excellent solutions have been proposed for these problems. However, to be best of our knowledge, there are few works which focus on the impact of background traffic on power efficiency of Wireless LAN stations. Our preliminary experiment shows that the power consumption of a mobile device increases by about 30% because of background multicast traffic. This power increase occurs whether stations join the multicast stream or not because multicast frames are treated as broadcast frames in IEEE 802.11 networks. FMS is a new power efficient mechanism defined in the IEEE 802.11v[2]. The overview of FMS is shown in Fig.1 (Original FMS). FMS defines a special unit named stream featured by a set of parameters such as MAC and IP addresses. APs transmit multicast that select a unique time interval for each stream. This time interval is larger than the original Delivery Traffic Indication Message (DTIM). A station may wake up at the interval specific to the multicast stream that the station wishes to join. FMS mechanism enables stations to avoid receiving unnecessary frames. However, FMS is not the optimal strategy because in FMS standard APs should transmit multicast streams which have the same delivery interval at the same time. Optimal choice and delivery pattern are out of scope of the standard and thus as shown in Fig.1 (Extended FMS), the power efficiency could be improved significantly by selecting the right interval and pattern for each stream. However, to decide the optimal delivery pattern, APs should consider many parameters, i.e. which stations to receive which streams, the number of multicast streams, the delivery interval, throughput, etc. We have modeled the delivery pattern and found that its computational complexity is $O(\alpha^N)$(α is a natural number) when brute-force search is employed. Thus, an excellent algorithm for the problem is needed.

In summary, our contribution is as follows: (1) Background multicast streaming traffic causes the increase of power consumption of mobile devices by about 28%. (2) Computational cost to decide the optimal delivery is $O(\alpha^N)$. (3) The optimal delivery strategy of FMS can result in power savings of stations' by at most 45%.

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2. BACKGROUND

We investigate the impact of multicast traffic on stations' power consumption. We set up the experiment environment based on Thiagarajan' s work[5]. We used a Galaxy nexus SC-04D as a station and Buffalo WZR-AGL300NH as an AP. We used IEEE 802.11a for the wireless network. To mea-

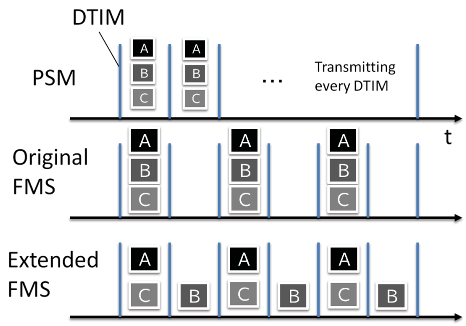

Figure 1: The timeline shows the frame transmission in three power saving mechanism.

sure the station's power consumption, we attached a small resistor serial to the power supply line. Measuring its voltage drops, we can calculate current using the Ohm' law. We also measured the battery voltage to calculate power consumption. The station is associated with the AP and the AP is connected to a PC via Ethernet. The PC transmits 960kbps multicast traffic destined for an unused group address to simulate the situation that station receives the stream in MAC layer but discard them after the station snoops into packets. We have conducted the experiment with or without the multicast stream. Each measurement lasted for 30 seconds and the result is an average of 10 measurements. The result shows that the power consumption was increased by about 28% when the AP transmits multicast frames. A Wireless LAN chip have Power Saving Mode (PSM) which enables the module to turn off its transceiver when there are no frames to transmit or receive (sleep). Though multicast streams prevented stations from sleeping and caused increased power consumption, multicast is by its nature a power efficient strategy to deliver the same content to multiple stations.

The most significant difference between FMS and PSM is the flexibility of delivery intervals of multicast streams. Again, Fig. 1 illustrates the timeline of both mechanisms. Although PSM regulates that APs should transmit every multicast stream in every DTIM, FMS still permits APs to modify the delivery intervals of multicast streams. In the Fig. 1(Original FMS), we assume that the transmission of the stream A has 2-slot intervals. Destination stations should wake up at the first slot to receive a DTIM beacon and the stream A, and they switch to sleep again in the second slot. The interval is decided by the negotiation between the AP and stations. So, several streams may share the same interval. In original FMS, APs must transmit required streams together with other streams that share the same interval and the stations will receive all frames transmitted in the same DTIM period. That results in unnecessary power consumption. On the other hand, Fig. 1 (extended FMS) describes the extended FMS mechanism. We permit APs to shift the transmission timing between interval slots even though the streams share the same interval. Therefore, APs are able to optimize the transmission pattern for better power efficiency. Since APs only shift the transmission timing, the optimization does not cause any overhead.

We have modeled FMS transmission to analyze stations' power consumption. We assume a simple network which contains one AP, M stations and N multicast streams. Stations and streams are numbered from 1 to M and N, respectively. In this paper, we only consider multicast frames. We left unicast frames, packet loss and AP's buffer overflow for future study. Our modeling is motivated by the Anastasi's work[3]. According to thier modeling formulation, stations' power consumption is the trade off between the number of stations' receiving frames and how often stations wake up. However, considering actual parameters, we can prove that the power consumption strongly depends on the number of frames received by the station. The intuitive reason is that multicast streams used for content streaming require a huge number of frames thus the impact of receiving frames is more significant. Moreover, the overhead of stations' waking up is insignificant. The overhead consists of receiving beacon frames and state transition of wireless LAN modules. Obviously, the number of receiving beacons is smaller than that of multicast frames. The overhead of state transition is also small because stations do not have to wake up to receive every DTIM beacon. Therefore, we can ignore these overheads and define the number of frames received by stations as a cost function C.

Let S_i denote the delivery interval of stream i and T denote the least common multiple of $S_i(i = 1 \text{ to } N)$. The delivery pattern has T_dT periodicity, where T_d is a period of DTIM beacons. Then, it is relevant that we limit the target period to $[t_1\ ,\ t_1 + T_dT]$ where t_1 is the initial time when the first DTIM beacon is transmitted. We assume that the AP buffers all the frames and transmits them on and after the next opportunity. This assumption can ease our analysis and it obeys the IEEE 802.11 standard. We also assume that the streams are of fixed sized frames and constant flows (the arrival rates are denoted by λ_i). Under the assumption, we can derive the mean of stream i frames' number which arrive in one DTIM period: u_i. u_i is denoted by $\lambda_i S_i T_d$.

Let t_k denote the time when kth DTIM beacon is transmitted and we define following binary variables. l_{ik} means whether AP transmits stream i in the period $[t_k, t_{k+1}]$. l_{ik} becomes 0 when stream i is not transmitted and becomes 1 when it is transmitted. Z_{ij} means whether station j receives stream i. Z_{ij} becomes 0 if station j does not receive stream i and becomes 1 if station j receive stream i.

Since we assume that the unicast flow does not exist, the stations keep active only when the AP indicates there are streams in the buffer which the stations want to receive. Then, let s_{jk} denote whether station j keeps active in the period $[t_k, t_{k+1}]$. s_{jk} is given by

$$s_{jk} = P_N(i, l_{ik} Z_{ij}) \tag{1}$$

where

$$P_N(i, x_i) = x_1 \vee x_2 \vee x_3 \vee ... \vee x_N \tag{2}$$

Now we obtain the whole number of received frames as follows

$$C = \sum_{k=1}^{T} \sum_{j=1}^{M} \sum_{i=1}^{N} s_{jk} l_{ik} u_i \tag{3}$$

C is the cost function to minimize the consumed power in the system. The variable in the equation is l_{ik}. Let o_i denote the first k which l_{ik} becomes 1. Considering the periodicity of streams in the interval S_i, the maximum of o_i should be $S_i - 1$. If $o_i = S_i$ were correct, the l_{ik} would

Streams	n1	n2~4	n5,6	n7,8
Throughput (λi)[bps]	2.4K	128K	256K	1M
Interval(Si)	4	5	3	2

STAs	m1 ~ m16
Receiving Stream	n1 and RANDOM from n2~n8

Figure 2: The simulation parameters. There are 8 streams and 16 stations.

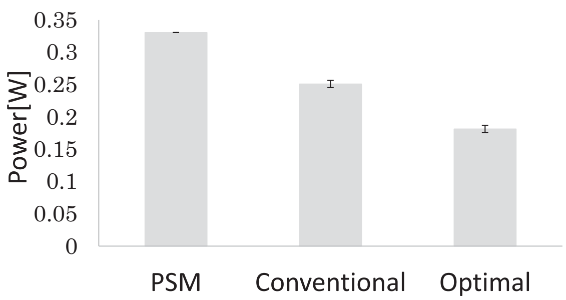

Figure 3: The NS2 simulation result. Power consumption of stations in three different conditions.

become 1 at $t_1 + T_dS_i, t_1 + 2T_dS_i, t_1 + 3T_dS_i....$ But the calculation period is $[t_1, t_1 + T_dT]$, then l_{ik} should be 1 at t_1 for the interval constraint. This contradicts the definition of o_i. Thus, each l_{ik} has S_i patterns for transmission and the whole combination pattern is denoted by $\prod_{i=1}^{N} S_i$. If we use brute-force search to solve the problem, the computational complexity becomes quite large:$\mathcal{O}(\alpha^N)$(α is a natural number). In addition, the calculation cost of C is also substantial because of the triple summations:$\mathcal{O}(MTN^2)$. The brute-force search is infeasible because the AP has a small computational resource. Since C includes the OR operation, Linear Programming (LP) cannot be adopted. Also, we have tried to utilize Dynamic Programming (DP) which is a well known algorithm to obtain the optimal solution. However, since the problem cannot be divided into correct subproblems, DP cannot be adopted. To our knowledge, the proper solution to the problem has not been proposed.

3. CASE STUDY

We investigate how the optimal delivery strategy can increase the power efficiency by simulation. We have implemented original and extended FMS on the network simulator NS-2. To analyze power saving mechanism, we adopt the Wireless LAN Power Management Extension patch[1]. It provides the basic power saving mechanism on both APs and stations. To our knowledge, there is no patch providing FMS mechanism, so we customized the patch for evaluating FMS. But we have implemented only transmission mechanisms rather than all FMS components because we cannot find documents which specify FMS implementation details. Even though our implementation is partial, the simulator is reliable because our focus is on the capacity of power consumption reduction.

We analyze a simple model: one AP and 16 stations in the network. The content server which provides certain contents and the content list in multicast streams is in the same network of the AP. Fig. 2 shows the list of streams and their throughputs. Evaluating all combinations of intervals and throughputs is a considerably tough work. Instead we evaluate a simple scenario which is, we believe, a more general case. All streams are at fixed speed traffic and of a fixed packet size (600Byte). We conduct the simulations for three delivery patterns: optimal FMS, conventional FMS and PSM. We have obtained the optimal pattern by using brute-force but we note that the calculation is quite heavy. The conventional pattern observes original FMS regulations. The stations consume power of 1.4W while transmitting frames, 0.9W while receiving frames, 0.8W in idle state, and 0.016W in sleep state[4]. Each simulation lasts 20 seconds and we show the result as an average of 100 simulation runs. The simulation results are shown in Fig. 3. As shown in the graph, the optimal delivery pattern reduces the consumed power of each station by about 28% compared to the Conventional FMS and about 45% compared to PSM. The result proves the power efficiency will be improved when the optimal delivery is achieved.

4. CONCLUSION AND FUTURE WORKS

We have the following findings: (1) the background multicast stream increases stations' power consumption by about 28%, (2) the computational complexity to solve the problem is $\mathcal{O}(\alpha^N)$ where α is a natural number, (3) Power can be reduced dramatically by adopting the optimal pattern of FMS. These findings motivated us to reduce the computational complexity. However, it is still challenging to decide the optimal pattern. APs should consider the number of streams and throughputs as well as the combination of stations and received streams. As a result, the calculation complexity would be too large for APs to conduct real time calculation. This will be the first priority in our future research.

5. ACKNOWLEDGMENTS

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