Abstract

Solution to Beacon Overhead in 802.11 Hotspot Environment

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Abstract– These days, a large number of APs are deployed in 802.11 hotspot environment. When we use a smartphone or laptop in a café near an avenue or in subway station, we find that a lot of APs are on Wi-Fi connection list. We closely checked problems that may occur in such occasions. We especially focused on the beacon frame transmitted periodically by APs. As the number of APs increases, the number of beacon frames intending to access wireless medium also increases. We expect that an increased number of beacon frames disturb data transmission. And we show the results of measurements which we performed packet capture using wireshark at Gangnam station and INMC(we regard these two spots as hotspot environments). We analyze the portion of airtime occupied by beacon frames at hotspot and we further show that large portion of airtime occupied by beacon frames has harmful effect on the data throughput.

And we show two factors of beacon frame for reducing airtime of beacon frame. The two factors are beacon interval and beacon transmission rate. When we change the value of these two factors, we should consider side effects. We look closely at the effects of these factors on airtime and the other sides.

Based on the analysis of beacon interval and beacon transmission rate, we propose algorithm that select the values of beacon interval and beacon transmission rate satisfying 3 constraints.

Keywords: Wireless LAN, Hotspot, Beacon Frame, Airtime, Beacon Interval, Beacon Transmission Rate,

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Chapter 1

Introduction

Most of studies about performance degradation in 802.11 hotspot environment point out that hidden node problem and a number of contending node cause packet collision which reduce data throughput.

But in this paper, we show that too many management frames and control frames can also be the reason that data throughput decreases in hotspot environment. Among management frames, we focused on beacon frame.

Beacon frame is periodically transmitted on every target beacon transmission time(TBTT) through contention-based manner. If the number of APs increases, the portion of airtime occupied by beacon frame also gets larger. This makes airtime for data transmission deficient and eventually data throughput decreases.

We measured the portion of airtime occupied by beacon frame by packet capturing using wireshark at Gangnam station. Through this measurement and NS-3 simulation, we point out that transmission of a lot of beacon frames has effect on data throughput.

The factors we take into account to reduce airtime of beacon frame are beacon interval and beacon transmission rate. Default values of beacon interval and beacon transmission rate of the most APs are 102.4 msec and 1 Mbps. The longer beacon interval and the higher beacon transmission rate, the smaller airtime beacon frame occupies. The matter is how to determine the values of beacon interval and beacon transmission rate we use. There are tradeoffs between beacon interval and packet delay that STA in power saving mode suffers, and between beacon transmission rate and AP coverage. We perform study on these tradeoffs.

Considering these tradeoffs, we show several constraints to pick appropriate values of beacon interval and beacon transmission rate. Finally, we propose algorithm that finds values of beacon interval and beacon transmission rate satisfying constraints. We also show applications of proposed algorithm to hotspot environment(Gangnam station).

Chapter 2

Measurement

To confirm the problem in 802.11 hotspot environment we predicted, we measured the number of AP s and airtime of beacon frame near Gangnam station in which numerous APs are deployed. Measurement program is wireshark. We perform the measurements at 5 locations near Gangnam station depicted in figure1 and the number of APs can be seen at each location is shown in table1.

Firgure1. Measurement locations

Location	# of APs
① Angelinus Cafe	82
② Subway exit 6	168
③ Waiting room (Subway)	68
④ McDonald	54
⑤ CGV ticket office	53

Table1. The number of APs

53 to 168 APs exist at each location in all 13 channels. We look closely the measurement at Subway exit 6 in which 168 APs are seen. This time we measured the number of APs in one channel. The result is show in table2.

location	# of APs		Air-time(ms)
	Total	Measured channel	Collision-free
Exit 6	168	42	84

Table2. measurement at Subway exit 6

42 APs are in the same channel and airtime means airtime used to transmit beacon frame in case of no collision. We assume transmission time per one beacon frame is 2 msec(beacon length =250 bytes, beacon transmission rate=1 Mbps). Beacon frames occupy 84 msec of 102.4 msec. That is definitely the problem. We can use only 18.4 msec of 102.4 msec for data transmission. It will degrade data throughput performance.

We performed an experiment to confirm the effect of excessive beacon airtime on data throughput. Figure2 is topology of experiment and table 3 is result of experiment. A STA is transmitting data with full load at 54 Mbps and neighboring APs are transmitting beacon frame periodically. Since we measure at 2 A.M. when there is no other data user, most of transmitted packets by them are beacon frames. We compare the two cases. The first case is the channel in which 30 APs are seen. And the second is the channel in which 9 APs are seen. The portion of airtime of beacon frames of 30APs is larger than that of 9 APs. And for sure, we confirmed the larger portion of airtime of beacon causes the lower data throughput.

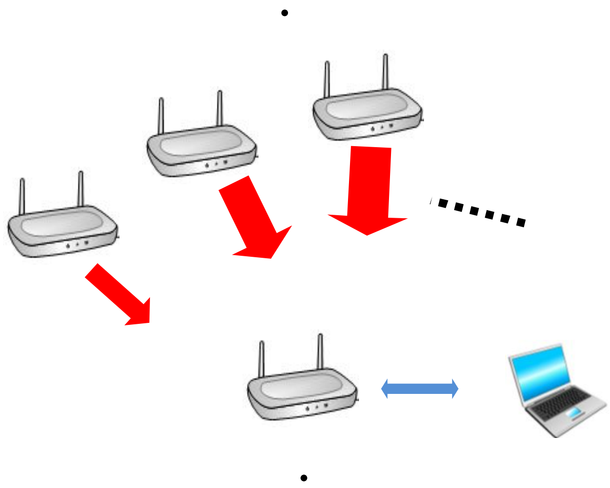

Figure2. Experiment topology

Measured channel	# of APs	% of air-time	Data throughput
1	30	21.9%	6.96 Mbps
6	9	2.97%	17.43 Mbps

Table3. Measurement result

Chapter 3

Factors for problem solving

In this section, we show the key factors to reduce airtime occupied by beacon frame. Those are beacon interval and beacon transmission rate. First, we show the effect of the two factors on beacon airtime and data throughput and finally we take close look at the tradeoffs of the two factors.

3.1 Effect on beacon airtime

These days, most APs broadcast beacon frame periodically at 1 Mbps every 102.4 msec. To reduce beacon airtime, we can transmit beacon frame at higher transmission rate and transmit beacon frame less frequently. Then we need to know how much airtime we can save when we use specific values of above two factors. Table 4 show the airtime per one beacon frame(T_{btx}) at every transmission rate we can use.

Mbps	1	2	5.5	11	6	9	12	18	24	36	48	54
T_{btx} (usec)	2080	1136	535	364	346	242	186	134	106	82	66	62

Table4. Airtime per one beacon frame(T_{btx}) at every transmission rate

We calculated T_{btx} as following.

T_{btx}= DIFS+1 slot time+(250*8/tx rate)

And if beacon interval is lengthened by n, the portion of beacon airtime becomes 1/n of the original airtime portion.

By configuring beacon interval and beacon transmission rate, we can reduce the portion of beacon airtime and improve data throughput performance. We performed simulations to confirm the effects of two factors on data throughput using the same topology shown in Figure2. Figure3 is the case of variable beacon transmission rates and figure4 is the case of variable beacon intervals.

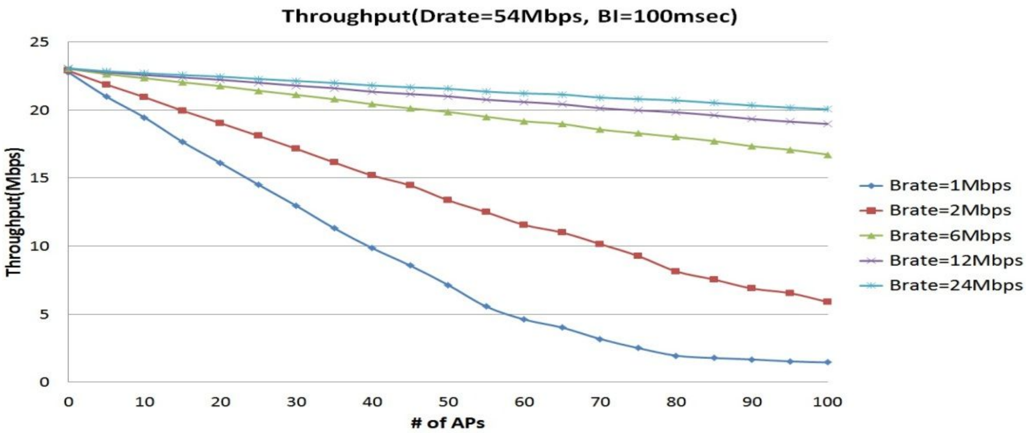

Figure3. Simulation results of data throughput with various beacon transmission rates

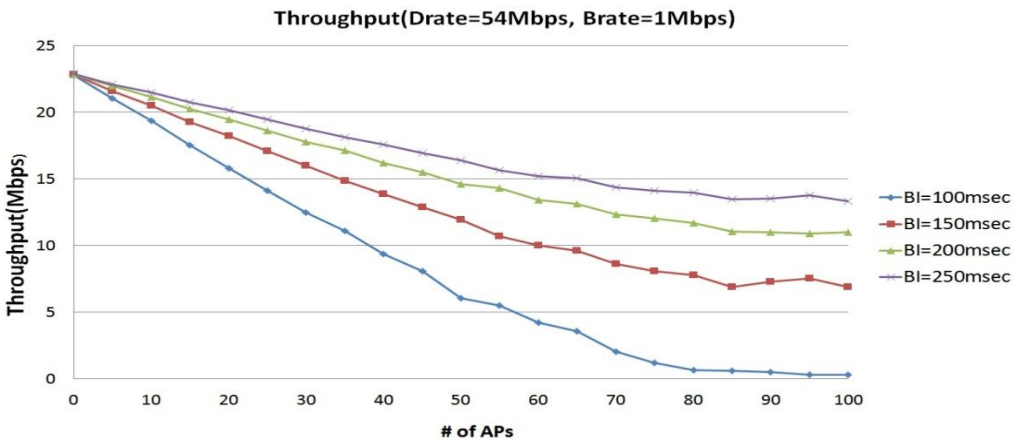

Figure4. Simulation results of data throughput with various beacon intervals

3.2 Tradeoffs of two factors

We have already commented that increasing the values of beacon interval and beacon transmission rate have side effects in introduction. We take a close look at these side effects to increase two factors with affordable performance degradation.

First, there is a tradeoff between beacon transmission rate and cell coverage. According to semi-open office environment, radius of cell coverage is shown in Table5.

Mbps	1	2	6(5.5)	9	12(11)	18	24	36	48	54
Coverage radius(m)	105	77	65	57	54	50	43	35	23	19

Table5. Cell coverage in case of every beacon transmission rate

Details of semi-open office environment are as following.

Path loss coefficient= 2 (for d <5 m),

3.3(for d >5 m)

Tx power=15 dBm, fading margin=10 dB.

So increasing beacon transmission rate should make allowance for smaller cell coverage.

Second, long beacon interval causes severe queueing delay. In hotspot environment, most of devices people use are smartphones operating in power saving mode during majority of time. When devices operate in power saving mode, dozing devices wake up every Target Beacon Transmission Time(TBTT) and receive beacon frame and previously queued data frame. If beacon interval is lengthened, longer time will take to receive queued data frame. Figure5 shows queueing delay of STA operating in power saving mode with various beacon intervals.

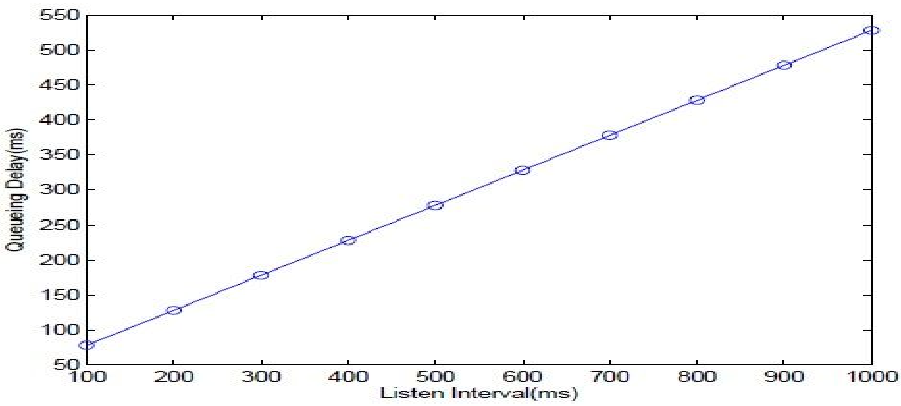

Figure5. Queueing delay with various beacon intervals

Chapter 4

Solution considering constraints

In this section, we propose algorithm selecting proper pair of beacon transmission rate and beacon interval. We find the pair maximizing expected throughput satisfying 3 constraints.

Expected throughput is the average throughput STA can get at random location in AP coverage. We need to assume two things for calculating expected throughput.

The first assumption is that STAs are distributed in coverage with even probability. In other words, the probability that STA is in specific region is proportional to the area. The second assumption is that all STAs in coverage transmit data with full load, so they have exact access faineess.

Expected throughput can be calculated as below when AP uses beacon transmission rate r.

$$\gamma_{Er} = \sum_{r=lowest\ tx\ rate\ in\ coverage}^{54\ Mbps} (\boldsymbol{a_r} \times \gamma_r \times \boldsymbol{t_r})$$

a_r: probability that link uses transmission rate r(portion of area in which STA uses transmission rate r)

Γ_r: real throughput in case of using transmssion rate r.

t_r: portion of airtime occupied by data packet transmitted through rate r.

Then, we show the graph of expected throughput in figure6.

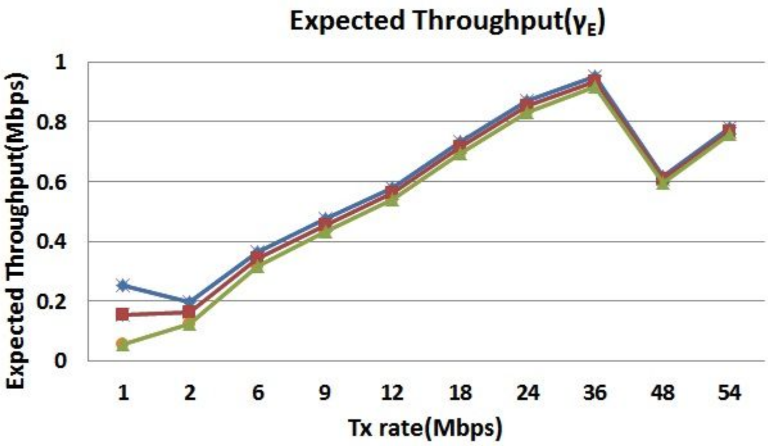

Figure6. Expected throughput of all transmission rates.

We introduce definitions and notations before we propose algorithm.

R*={1, 2, 5.5, 11, 6, 9, 12, 18, 24, 36, 48, 54} is a set of beacon tx rates,*

I*={102.4x n, n∈****N****} is a set of beacon intervals.*

*d(i) is queueing delay of STA in power saving mode with beacon interval i∈****I****,*

*c(r) is radius of cell coverage when we use tx rate r∈****R****.*

A(r, i, n_{AP}) means percentage of beacon airtime in case of r and i.

α is maximum value of percentage of allowable beacon airtime(%).

β is minimum radius of cell coverage AP installer requires(m).

δ is maximum value of allowable queueing delay bound(msec).

n_{AP} is the number of associable APs.

The proposed algorithm is following. Threshold values α, β and δ are given by AP deployer or network designer.

Initialize) $r \in \mathbf{R}$, $i \in \mathbf{I}$

Input α, β and δ

Find i

Step1) arg max $d(i)$

Subject to $d(i) \le \delta$

Find r

Step2) Form $\mathbf{R_1}$ from $\mathbf{R}$

$\mathbf{R_1}=\{r \mid c(r) \ge \beta, r \in \mathbf{R}\}$

Step3) Form $\mathbf{R_2}$ from $\mathbf{R_1}$

$\mathbf{R_2}=\{r \mid A(r, i, n_{AP}) \le \alpha, r \in \mathbf{R_1}\}$

Step4) arg max Γ_E

AP installer configures 3 values, α, β and δ. In step1, we find the values of beacon interval satisfying queueing delay bound. From step2 to step4, we find the value of beacon transmission rate. In step2, we find the values satisfying coverage requirement. In step3, we find the values satisfying airtime constraint. Finally in step4, we select the beacon transmission rate maximing expected throughput.

Chapter 5

Conclusion

In this paper, we paid attention to beacon frame that causes shortage of airtime for data transmission in 802.11 hotspot environment. And we confirmed that transmission of a number of beacon frames decreases data throughput. To improve performance of data throughput reduced by transmission of beacon frame, we can configure beacon interval and beacon transmission rate considering tradeoffs. we proposed algorithm selecting the values of beacon interval and beacon transmission rate satisfying given constraints. Using this algorithm, we can reduce the portion of airtime occupied by beacon frame and improve data throughput in hotspot environment.

Bibliography

[1] IEEE STD 802.11-2007(Revision of IEEE Std 802.11-1999), pp.C1-1184, June 12 2007.

[2] R. Raghavendra, E.M. Belding, K.Papagiannaki and K.C. Almeroth, “Unwanted link layer traffic in Large IEEE 802.11 wireless networks,” *IEEE Trans.Mobile Computing*, Vol.9, Issue 9, pp. 1212-1225, Sep. 2010.

[3] N.R. Prasad, “IEEE 802.11 system design,” *IEEE International Conference on Personal Wireless Communications*, 2007

[4] Hongyan Lei, Arne A. Nilson, “Queueing Analysis of Power management in the IEEE 802.11 Based Wireless LANs,” *IEEE Trans.Wireless Communications*, Apr. 2007

한글 초록

본 논문에서는 WLAN Hotspot 환경에서 다수의 Beacon Frame 이 전송됨으로 인한 문제점을 살펴보고 실험으로 확인하였다. 앞에서 설명한 문제점을 해결하기 위해서는 Beacon 전송주기와 Beacon 전송률을 변화시켜야 하는데 이 때 나타나는 여러 현상과 효과를 고려해서 변화시켜야 한다. 이러한 것들을 모두 고려하여 Beacon 전송이 차지하는 Airtime 을 줄이는 것이 목표이다. 여기서 우리는 기대 수율을 제안하며, 실제 환경에서 감안해야 할 제한조건들을 만족시키면서 기대 수율을 최대화하는 Beacon 전송주기와 Beacon 전송률을 선택하는 알고리즘을 제안한다.

주요어 : WLAN, Hotspot, Beacon Frame, Airtime, Beacon 전송주기, Beacon 전송률

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