IP 기반의 매크로/펨토 셀룰러 망에서 시스템의 안정성 향상을 위한 효과적인 채널 분배 기법

Efficient Channel Split Strategy for System Stability in IP Based Macro/Femto Cellular Networks

박경민*, 김영용*

Kyung-Min Park*, Young-Yong Kim*

요 약

본 논문은 매크로/펨토 셀룰러 망에서 모든 셀들 간의 서비스 공평성을 유지함으로써 시스템을 안정화하고 데이터 전송속도를 향상시키기 위한 채널 분배 기법을 제안한다. 특히 매크로셀과 펨토셀 간에 분배하는 채널의 비율이 시스템에 주는 구체적인 영향을 파악하기 위하여 IP 기반의 매크로/펨토 셀룰러 망에 대한 대기행렬 모형을 제시한다. 이를 바탕으로 실질적인 채널 분배 전략을 제안하고, 실험을 통하여 다양하게 변화하는 시스템 환경에 따라 제안 기법의 동작을 분석한다. 또한 그 결과를 통하여 효율적인 시스템 구조의 설계 방향에 대하여 논의한다.

Abstract

In the macro/femto cellular networks, the portion of channels assigned to each cell is a critical factor which sets the stability and the performance of the whole system. To grasp the concrete influence that the channel split portion have on the system, we present the queueing model for IP based macro/femto cellular networks, and find the stability conditions. Additionally we provide the strategy to decide the portion of channels allocated to each cell. Through the experiments, we prove that the proposed strategies operate feasibly in various network environments, and on the basis of these results we discuss the efficient system structure plan.

Keywords: Macro/femto cellular networks(매크로/펨토 셀룰러 망), queueing analysis(대기행렬 분석), stability guarantee(안정성 보증), channel split strategy(채널 분배 전략)

I. Introduction

Recently as the use of IP based services and new applications through cellular networks rapidly grows, the interest of macro/femto cellular networks which improve the cell capacity especially in indoor or densely populated areas has increased [1], [2], [3]. However, the unsophisticated setup of femto base stations(fBSs) by users has some risks to make the system unstable and fallen in service quality. Therefore, an efficient policy for radio resource and administration is essential for stable services in femtocells.

The radio resource management(RRM) policy for a stable system has various approaches such as transmission power setting, channel allocation, and interference mitigation. Some aims the system stability by minimizing the number of mobility events for the coverage adaptation [4], while other schemes [5], [6] do based on the hybrid regions of coverage according to interference level. However, the system stability cannot be considered separately with queue stability which are connected to packet arrival and channel states of each cell.

In this paper, we focus on the stability problem of macro/femto cellular systems in terms of minimizing the packet delay. Our algorithm provides a channel split strategy among macrocell and femtocells to guarantee fairness among cells. In addition, the conditions for system stability are represented reflecting the wireless link environment and the traffic load of each cell.

Our algorithm is able to catch up the variance of environment, and offer a deployment strategy for effective cell structure which can be exploited by individual user. Our organization is as follows: we find the condition of stable services through the queueing model for the macro/femto cellular networks in Section II, and provide a channel split strategy in Section III. We analyze the performance changes in relation to the proposed strategy and system environments, and find an effective cell structure plan in Section IV. Finally conclusions are made in Section V.

Ⅱ. System Model

We consider the wireless cellular system consisted of a single macrocell and femtocells in Fig. 1. Macro base station(mBS) and m fBSs share N channels. $N\alpha$ channels are assigned to fBSs with frequency reuse factor K, where α satisfies $0 \leq \alpha \leq 1$. The coverage area of a macrocell is S, and every femtocell each occupies same area, s. We assume that the coverage of femtocells does not overlap each other and $S \geq ms$ is satisfied. Mobile stations located in the coverage of femtocells are served from the femtocells.
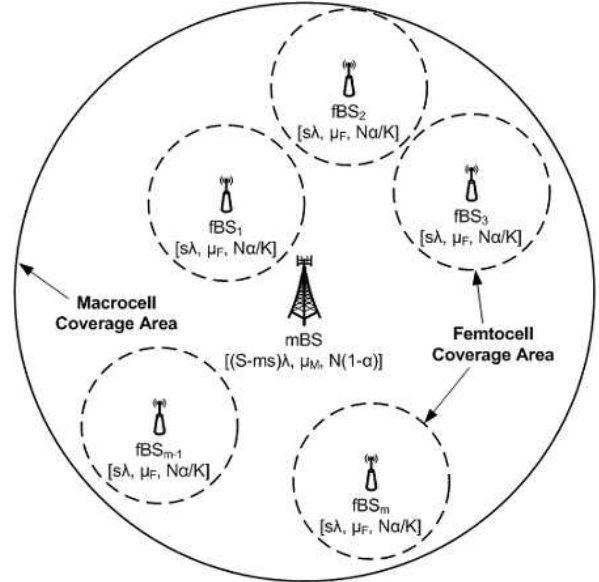

그림 1. 매크로/펨토 셀룰러 망 구조.
Fig. 1. Macro/femto cellular network structure.

We apply $M/M/1$ queueing model to this system in [7], and assume that mobile stations are uniformly deployed. Accordingly it is reasonable that the packet arrival rate at each base station is proportional to its cell coverage area. The average packet arrival rate for unit area is λ, which accords a Poisson process. Hence the packet arrival rate at a macrocell is $(S-ms)\lambda$, and that of a femtocell is $s\lambda$.

In [8], for mobile station i using channel n with M quadrature amplitude modulation (MQAM) modulation, if $M \geq 4$ and $0 \leq SINR_{in} \leq 30dB$, the bit error rate($BER$) is bounded by

$$BER \leq 0.2e^{-1.5SINR_{in}/(M-1)} \qquad (1)$$

For a given BER on a packet transmission link, the maximum number of bits in a symbol, $q_{in} = \log_2 M$, is obtained as

$$q_{in} = \log_2(1 + SINR_{in}/\Gamma) \qquad (2)$$

where $\Gamma = -\ln(5BER)/1.5$. Accordingly the achievable data rate r_{in} is calculated as

$$r_{in} = \frac{q_{in}}{T_S} = \frac{B}{N}log_2(1 + \frac{SINR_{in}}{\Gamma}) \qquad (3)$$

where T_S denotes the symbol duration, and B is the total system bandwidth. If average packet length is l, the packet service rate is $\mu_{in} = r_{in}/l$ for mobile station i with channel n. By averaging packet service rates for mobile stations in each cell, we get average packet service rates μ_M and μ_F at a macrocell and all femtocells for one channel. In our queueing model, the packet service times are assumed as exponential random variables with mean $1/\mu_M$ and $1/\mu_F$. Hence in a macrocell and femtocells, the mean packet service rates for own channels each are $N(1-\alpha)\mu_M$ and $(N\alpha/K)\mu_F$.

In $M/M/1$ queueing systems, from the packet arrival rate and the service rate at each cell, we can derive the average packet sojourn times, T_M and T_F, of packets in the transmitting system at a macrocell and femtocells.

$$T_M = [N(1-\alpha)\mu_M - (S-ms)\lambda]^{-1} \qquad (4)$$

$$T_F = [(N\alpha/K)\mu_F - s\lambda]^{-1} \qquad (5)$$

For the system stability, the packet arrival rates at each cell should be smaller than the packet service rates. Thus $(S-ms)\lambda < N(1-\alpha)\mu_M$ and $s\lambda < (N\alpha/K)\mu_F$, which determine the effective range of α.

$$Ks\lambda/(N\mu_F) < \alpha < 1-(S-ms)\lambda/(N\mu_M) \qquad (6)$$

As α approaches to $1-(S-ms)\lambda/(N\mu_M)$,

T_F infinitely increases, and as α nears $Ks\lambda/(N\mu_F)$, T_F infinitely increases. Therefore by selecting α in range (6), we can guarantee the system stability. Based on this condition, in next session, we propose the channel distribution strategy to minimize T_M and T_F. It allocates channel to reduce packet service delays with considering traffic loads and channels environments at the macrocell and femtocells.

Ⅲ. Channel Distribution

In the packet based queueing system, the packet sojourn time in the system is directly connected with the service delay for users. Moreover the large packet sojourn time in $M/M/1$ queueing system causes the increase of packet drop probabilities in the real system with limited buffer size. Therefore the control of the packet sojourn time is necessary to reduce the service delay and improve stability. By deciding the number of channels assigned to the femtocells in Fig. 2, the packet sojourn time control in each cell is practicable. We basically aim to guarantee the fairness among users in a macrocell and femtocells. Especially we consider min-max fair strategy for the average packet sojourn time at each cell, which minimizes the packet sojourn time at the cell serving with the maximum average packet sojourn time. It provides the fair services by improving the quality of services for underprivileged users.
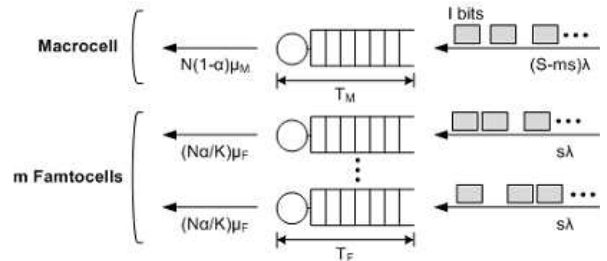

그림 2. IP 기반 매크로/펨토 셀룰러 망의 대기행렬모형
Fig. 2. Queueing model for the IP based macro/femto cellular networks.

The fairness optimization problem to minimize the maximum packet sojourn time is formulated as follows.

$$\min_\alpha [\max(T_M, T_F)] \qquad (7)$$

where α is in the range (6).

In Appendix, we proved that the min-max fairness problem for T_M and T_F is simplified to the problem searching for the solution of equation $T_M = T_F$. Therefore the following equation is formed.

$$N(1-\alpha)\mu_M - (S-ms)\lambda = (N\alpha/K)\mu_F - s\lambda \qquad (8)$$

By numerical procedures, the optimal portion of channel assigned to femtocells, α^*, is obtained.

$$\alpha^* = \frac{\mu_M - [S-(m+1)s]\lambda/N}{\mu_F K + \mu_M} \qquad (9)$$

In this strategy, as the number of femtocells increase, more channels are allocated to femtocells. On the contrary, if the packet transmission rates at femtocells or packet arrival rates are high, femtocells receive less channels.

From (4), (5), and (9), we drive min-max fair optimal packet sojourn time, $T^* = T_M^* = T_F^*$.

$$T^* = \frac{\mu_F + \mu_M K}{N\mu_F\mu_M - [S-ms]\lambda\mu_F - s\lambda K\mu_M} \qquad (10)$$

Note that (10) represents that with the fixed packet arrival rates as the number of femtocells or packet service rates at each cell increase, the optimal packet sojourn time decreases. However as more femtocells are installed, the interferences among femtocells increase and packet service rates at femtocells are dropped. Moreover if the channel reuse factor among femtocells increases, then while the packet sojourn time increases, the interferences among femtocells decrease and packet service rates at femtocells grow. Therefore we need to definitely analyze the effect that the number of femtocells and the channel reuse factor have on system performances with respect to the amount of traffics.

Ⅳ. Simulation Results

We consider a radius of macrocell is 200m, and femtocells with a radius of 10m are located in the macrocell coverage. The uniformly distributed users generate the regular amount of traffic. Transmission power of mBS is 40dBm, and fBS power is taken as 20dBm. An adaptive modulation scheme as (2) is used, and the 64QAM is maximally available. We experimented as changing the number of femtocells for different ρ and K, where $\rho = S\lambda/(\mu_M N)$ is the traffic intensity when there is no femtocell in a macrocell, [5].
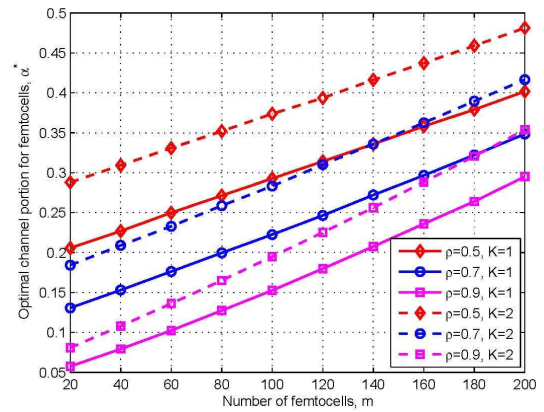

그림 3. 펨토셀에 대한 최적의 채널 할당 비율, α^*.
Fig. 3. Optimal channel portion for femtocells, α^*.

At first, Fig. 3, Fig. 4, Fig. 5 show that as more femtocells are installed in a macrocell, the optimal channel portion for femtocells increases, the optimal packet sojourn time is sharply decreases, and the average number of bits transmitted in a symbol at femtocells drops because of the interference increments among

femtocells.

Second, when the traffic intensity grows, α decreases in Fig. 3. Because in a case of high traffic loads it is advantageous on fairness improvements of whole networks that more channels are assigned to macrocell with relatively bad radio environments and less channels are allocated to femtocells with good radio conditions. In high traffic states packet sojourn time of queueing systems necessarily increases. Proposed strategy insures the stability by distributing channelsas system environments, and the gap of T^* caused by different ρ decreases when m is large.
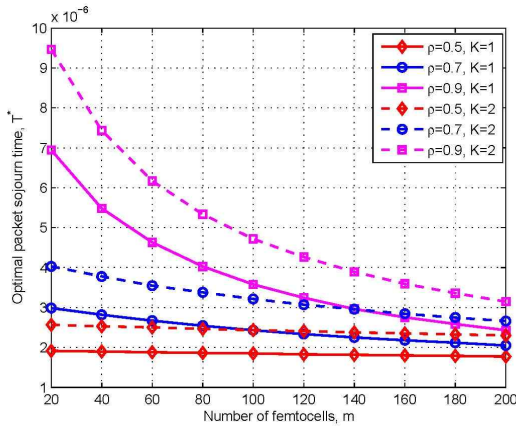

그림 4. 최적의 패킷 서비스 소요 시간, T^*.
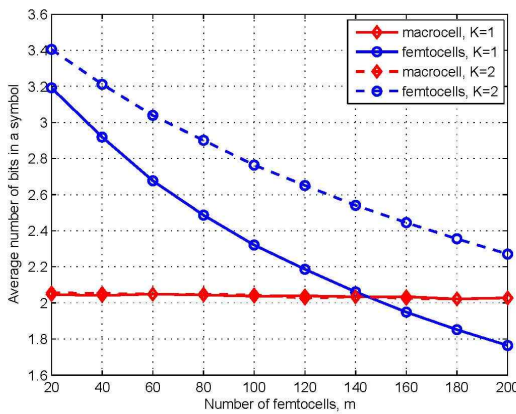Fig. 4. Optimal packet sojourn time, T^*.

그림 5. 한 심볼 당 전송되는 평균 비트 수.
Fig. 5. Average number of bits transmitted in a symbol.

Thirdly, if the channel reuse factor of femtocells is 2,

femtocells need more channels, and as Fig. 5 the average number of bits transmitted in a symbol at femtocells increases due to the decrease of interferences among femtocells. However this effect is not enough to obstruct the increase of T^* as Fig. 4 by decreasing of total system throughput owing to the lose of available channels at each femtocell. Consequently as more femtocells are installed with $K = 1$, the system performance is improved through proposed strategy.

V. Conclusion

In this paper, we presented the queueing model for IP based macro/femto cellular networks, and found the stability condition. Based on this analysis, we provided the channel split strategy for each cell to improve system fairness and performance. In experimental results, we analyzed the operation of the proposed strategy in different system environments, and discussed an efficient cell structure. As future works we will analyze the results that the other optimization strategies, such as a throughput maximizing strategy, bring on, and develop the channel assigning scheme in dynamically changing network environments.

Appendix

T_M is the strictly increasing function with respect to α in range (6), and T_F decreases strictly. As α approaches to $Ks\lambda/(N\mu_F)$, T_M converges and T_F infinitely increases. In contrary, as α approaches to $1 - (S - ms)\lambda/(N\mu_M)$, T_M infinitely increases and T_F converges. Therefore in range (6), T_M and T_F should meet at one point $\hat{\alpha}$. It is obvious that $T_M \geq T_F$ when $\alpha \geq \hat{\alpha}$, and $T_M < T_F$ when $\alpha < \hat{\alpha}$.

If $T_M \geq T_F$, T_M has the minimum value when $\alpha = \hat{\alpha}$. Moreover if $T_M \leq T_F$, T_F reaches to the

minimum value when $\alpha = \hat{\alpha}$. Consequently for all cases, the minimum value of larger one between T_M and T_F is obtained when $\alpha = \hat{\alpha}$. That is optimization problem (7) is equivalent to the problem searching for the solution of equation $T_M = T_F$.

Acknowledgment

References

[1] H. Claussen, "Performance of macro- and co-channel femtocells in a hierarchical cell structure," *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* pp. 1-5, 2007.

[2] H. Claussen,"Self-optimization of coverage for femtocell deployments," *Wireless Telecommunications Symposium,* pp. 278-285, 2008.

[3] R.Y. Kim, J.S. Kwak and K. Etemad,"WiMAX femtocell: requirements, challenges, and solutions," *IEEE Communication Magazine,* vol. 47, issue 9, pp.84-91, 2009.

[4] H. Claussen, L. T. W. Ho, and L. G. Samuel, "Self-optimization of coverage for femtocell deployments," *Wireless Telecommunications Symposium,* pp. 278-285, 2008.

[5] V. Chandrasekhar, J. G. Andrews, and A. Gatherer, "Femtocell networks: a survey," *IEEE Communications Magazine,* vol. 46, pp. 59-67, 2008.

[6] I. Guvenc, M. Jeong, F. Watanabe, and H. Inamura, "A hybrid frequency assignment for femtocells and coverage area analysis for co-channel operation," *IEEE Communications Letters*, vol. 12, pp. 880-882, 2008.

[7] A. L. Garcia, {\em Probability and Random Processes for Electrical Engineering}, *Addison Wesley*, 1994.

[8] A. J. Goldsmith and S.-G. Chua, "Variable-rate variable-power MQAM for fading channels," *IEEE Transations on Communications,* vol. 45, pp. 1218-1230, 1997.

박 경 민(朴京旻)

2005년 2월 : 연세대학교 전기전자공학과 (공학사)
2005년 3월~현재 : 연세대학교 전기전자공학과 (통합과정)
2011년 3월~현재 : (주) LG전자 연구원
관심분야 : 펨토셀 시스템, Self-organized 네트워크

김 영 용 (金泳龍)

1991년 2월 : 서울대학교 전자공학과 (공학사)
1993년 2월 : 서울대학교 전자공학과 (석사)
1999년 : The University of Texas at Austin 전기 및 컴퓨터공학과 박사
2000년~현재 : 연세대학교 전기전자공학과 교수
관심분야 : 차세대 이동통신 시스템, 무선네트워크