Throughput Performance of Quantized Proportional Fair Scheduling with Adaptive Modulation and Coding

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Contents

- Introduction
- System model
- Numerical results
- Conclusions
Introduction
Background

- Since the utilization of multiuser diversity (MD) in wireless networks can increase the information theoretic capacity (ITC), much attention has been paid to scheduling algorithms exploiting MD.

- MD is a diversity existing between the wireless channel states of different users.

- MD comes from the fact that the wireless channel state processes of different users are usually independent for the same shared medium.
Scheduling algorithms exploiting MD

- For example, MD can be exploited in such a way that the scheduler in the BS (Base Station) selects the MS (Mobile Station) whose received SNR is the best, and transmits packets to the selected MS.
- This algorithm maximizes ITC of the overall system, but it is highly unfair.
Proportional Fair (PF) scheduling

- To solve this unfair problem, proportional fair (PF) was proposed.
- PF considers the normalized SNRs of MSs (defined by the received SNR / the average received SNR), and selects the MS whose normalized SNR is the largest.
Quantized PF (QPF) scheduling

- In practice, probably the normalized SNR values are *quantized*, the quantized normalized SNR values are reported to the BS by MSs, and the PF scheduling is performed based on the quantized normalized SNR values.
- This PF scheduling is called the **QPF (Quantized PF)** scheduling.
ITC vs Throughput in real wireless networks

- So far, assuming a logarithmic rate model, ITC under scheduling algorithms exploiting MD has been studied.
- ITC is theoretical upper bound of bit rate where information can be sent with arbitrarily low probability of error.

In many cases, throughput achieved in real wireless networks is very different from and is much less than ITC obtained under the assumption of logarithmic rate model.
Rate function in real wireless networks with AMC

- Many real wireless networks employ adaptive modulation and coding (AMC) scheme where multiple modulation and coding modes can be used and one of them is selected depending on the received SNR.
- Rate function of AMC is very different from logarithmic rate model.

In order to examine the usefulness and characteristics of QPF in real wireless networks, we should study throughput performance under more realistic rate function model rather than ITC under logarithmic rate function model.
What we do in this study

- Consider a wireless network consisting of a BS and MSs where QPF scheduling and AMC scheme are employed.
- Focus on downlink transmission and analyze throughput performance at the downlink.
- Obtain the expression of normalized throughput under QPF with AMC.
- For comparison, further obtain the expression of normalized throughput under PF with AMC and that under round-robin (RR) with AMC.
- Also provide numerical results to investigate the usefulness and characteristics of QPF with AMC.
System Model
System model

- A wireless network consisting of a BS and $K$ MSs.
- QPF and an AMC scheme are employed.
- Focus on downlink transmission and analyze throughput performance at the downlink.
Channel model

- We assume that the downlink channel of MS is described by a flat **Rayleigh fading channel** model.
- Time axis is divided into physical (PHY) frames of equal size $T_f$ (sec) and time index is given by $t=0,1,2,...$.
- PHY frame duration $T_f$ is considered to be unit time in our model.
The received SNR process \( \{Z^{(i)}(t)\} \) \( (t = 0, 1, \ldots) \) of MS \( i \) \( (i=1,\ldots,K) \) is a stationary process for any \( t \) is according to the following exponential distribution:

\[
P\{Z^{(i)}(t) \leq x\} = 1 - \exp\left(-x/\bar{Z}^{(i)}\right)
\]

where \( \bar{Z}^{(i)} \) denotes the average received SNR of MS \( i \).

We assume that the received SNR process of the \( K \) MSs are independent with each other.
QPF scheduler

- Under QPF, the normalized SNR processes \( \{z^{(i)}(t)/\bar{z}^{(i)}\} \) of MSs are considered.
- Each MS quantizes or partitions the entire normalized SNR range into \( L \) grades with quantization thresholds (QT) denoted by \( \{\gamma_l\}_{l=0}^L \) with \( \gamma_0 = 0, \quad \gamma_l < \gamma_{l+1} \) (\( l = 0, \ldots, L - 1 \)) and \( \gamma_L = \infty \).
- The normalized SNR process of MS \( i \) is in the \( \ell \)th (\( \ell=0,\ldots,L-1 \)) grade at \( t \) if \( \gamma_l \leq z^{(i)}(t)/\bar{z}^{(i)} < \gamma_{l+1} \).
- MSs with the normalized SNR values larger than $\gamma_1$ report their **SNR grades** to the BS.
- The scheduler considers MSs whose SNR grades are highest as candidates for transmission. If more than two MSs have the highest grade, the scheduler randomly selects one of them for transmission.
- Scheduling is performed PHY frame-by-frame.
AMC

- AMC scheme partitions the entire SNR range into $M$ transmission modes with boundary points denoted by $\{\xi_m\}_{m=0}^{M+1}$ with $\xi_0 = 0$, $\xi_m < \xi_{m+1}$ ($m = 0, \ldots, M$) and $\xi_{M+1} = \infty$.

- If $\xi_m \leq z^{(i)}(t) < \xi_{m+1}$, AMC controller for MS $i$ uses the transmission mode $m$ of the AMC at time $t$.

- When transmission mode $m$ is used, $d_m$ packets are mapped into a PHY frame and transmitted simultaneously in the corresponding PHY frame.
Packet error rate

- Packet error rate (PER) is expressed as a function of the transmission mode selected by the AMC controller and SNR.
- Let \( \text{PER}_n(\gamma) \) denote the PER when the mode \( n \) is used and the received SNR is equal to \( \gamma \).
- \( \text{PER}_n(\gamma) \) can be approximated as

\[
\text{PER}_n(\gamma) \approx \begin{cases} 
1 & (0 < \gamma < \gamma_{pn}), \\
 a_n \exp(-g_n \gamma) & (\gamma \geq \gamma_{pn}), 
\end{cases}
\]

where \( a_n, g_n, \) and \( \gamma_{pn} \) are the mode-dependent parameters and are given in Table I.
Numerical Results
Numerical results

- Investigate normalized throughputs under QPF with AMC and Compare them with those under PF or RR with AMC.

- Normalized throughput is Average number of packets which can be successfully sent to an MS during a unit time $T_f$.

- AMC with 7 modes shown in Table I is employed and the boundary points for the AMC scheme are determined by the method presented in [5].

- Difficult to determine the optimal QT (excluding the case of $L=2$). We use the Nelder-Mead Simplex algorithm with trial and error.
Effect of # of quantization levels

- Fig. 1-3 display the normalized throughput of MS under the QPF with AMC as a function of the number of its quantization levels.
- For comparison, Fig. 1-3 also show the normalized throughput under PF with AMC and the normalized throughput under RR with AMC.
Fig. 1: Normalized throughput (Ave.SNR=15dB, K=30)
Fig. 2: Normalized throughput (Ave.SNR=20dB, K=20)
Fig. 3: Normalized throughput (Ave.SNR=20dB, $K=30$)
Observation

- Normalized throughput under QPF with AMC increases with # of quantization levels.
- QPF with AMC can enhance the throughput performance, compared to RR with AMC.
- With a relatively small number of quantization levels, QPF with AMC can achieve almost same throughput performance as PF with AMC.
Effect of QT (quantization thresholds)

- For the simplicity of discussion, we limit ourselves to the case of $L=2$, i.e., # of quantization level=2.
- We here consider the following QPF with AMC:
  $\text{QPF}(\text{zdB}, k)$: QT is optimized for the condition that the average SNR and the number of MSs are equal to $\text{zdB}$ and $k$, respectively.
- Fig. 4 displays the normalized throughputs for QPF(20dB, 20), QPF(20dB, 30), QPF(30dB, 20) and QPF(30dB, 30) as a function of the average SNR.
- In Fig. 4, # of MSs is set to 30.
- For comparison, Fig. 4 also shows the normalized throughput under PF and that under RR.
Fig. 4: Normalized throughput for $K=30$
Observation

- Normalized throughputs under QPF increase in a discontinuous fashion with the increase of the average SNR.
- This occurs due to the combination of the discontinuity in the AMC and the quantization of the received SNR.
- More specifically, when a (not normalized) QT $\tilde{z}^{(i)} \gamma_n$ ($n = 1, \ldots, L$) moves from one AMC mode to another AMC mode with the change of the average SNR, the discontinuous change of the normalized throughput occurs.
- Normalized throughput under QPF greatly depends on the value of QT.
- If the actual average SNR is quite different from the average SNR where QT is optimized, the throughput performance is considerably degraded.
- In particular, if the actual average SNR is somewhat smaller than the average SNR where the QT is optimized, the enhancement of the throughput performance by using QPF is very limited.
Conclusion
Conclusion

- We analyze the throughput performance under QPF with AMC at the downlink.
- Numerical results show that QPF with AMC can enhance the throughput performance, compared to RR with AMC.
- However, if the actual average SNR is somewhat smaller than the average SNR where QTs are optimized, the enhancement of the throughput performance by using QPF is very limited.
- Therefore, we should notice that to utilize the potential ability of QPF, we need to carefully determine QTs.