Performance of Hybrid ARQ on Dual-Branch Diversity Receiver in Rayleigh Fading Channel

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***Abstract*—Error control techniques in wireless links such as Automatic Repeat Request (ARQ) and Forward Error Correction (FEC) are still quite effective approaches in the improving system throughput in particular in time—varying channel environments. In this paper, a dual-branch selection diversity receiver of combining Selective Repeat–ARQ scheme and BCH channel coding (hybrid ARQ) in mobile cellular networks like UMTS is proposed. The aim is to provide maximal achievable throughput when a predefined channel code is employed under various Rayleigh fading channel conditions. Both spatially uncorrelated and correlated antenna branches are investigated for identical and non-identical channels. The numerical results show that significant redundancy coding has a reasonable effect on the overall throughput performance. In contrary, the channel coding influences significantly on the lower range of operating channel SNR in the selection combining receiver when identical and non-identical correlated antenna branches are considered.**

I. INTRODUCTION

UMTS (Universal Mobile Tele-communication System) network based on Wideband Code Division Access (WCDMA) provides a clear evolution path to 4G high speed packet access (HSPA). In such packet based wireless communication system, the downlink has been developed for high data rate transmission up to 14 Mbps (and 5.76 Mbps in uplink) [1]. To achieve a high reliability in such cellular systems, diversity techniques are popular used at several layers of the network stack to combat variability in performance and provide reliability over unreliable time-varying channels. When the channel performance is good, a higher information rate can be sent; and when it is bad, it needs to add more reliability and sends at a lower information rate. The reliability techniques may involve two categories (1) error control schemes such as Automatic Repeat reQuest (ARQ) protocols [2] [3], Forward-Error-Correction (FEC) strategies, and hybrid ARQ that adds both Error-Detection code (ED) and FEC information to each message prior to transmission like soft-combining in UMTS [4] and incremental combining in HSPA using punctured 1/3 Turbo code [1]; and (2) diversity transmission and reception schemes with different modes (e.g. time, frequency, space, etc.); that both categories can provide more sophisticated throughput performance in time-varying channel environments [5] [6].

ARQ protocols generally can achieve a high reliability when erroneous packet is detected using error detection code such as a cyclic redundancy check (CRC). A retransmission request is sent to the transmitter over a feedback channel until an error-free reception is observed. More specifically, there are three basic ARQ protocols: stop-and-wait (SW), go-back-N (GBN), and selective-repeat (SR). Among all ARQ schemes, SR is reported to show the best throughput performance [7] and thus it is interesting to analyze and investigate its behavior in order to have an upper limit on the throughput performance that any ARQ protocol can achieve in practice. FEC scheme is also widely used in communication to detect and correct errors. It is proved to be efficient if the type of errors is known and errors do not exceed the maximum correction capacity of FEC. For example, (511, 493, 2) Bose-Chaudhuri Hochquengh (BCH) FEC can correct 2 bits of random errors per packet. However, the problem of FEC that it cannot efficiently handle burst errors. To solve this problem, some systems use interleaving technique which may introduce a large delay, and such delay is not suitable for real-time video communication systems [8].

On the other hand, the combination of ARQ and FEC reduces the number of retransmissions and yields three types of Hybrid ARQ schemes (HARQ I, HARQ II, and HARQ III) in which error correction followed by error detection is applied every received packet [9] [4]. For example, in HARQ I, when erroneous received packets are discarded NACK is sent to transmitter, and the entire packet is then retransmitted. This version adds both ED and FEC information to each packet prior to transmission. When the coded data block is received, the receiver first decodes the error-correction code. If the channel quality is good enough, all transmission errors should be correctable, and the receiver can obtain the correct data block. If the channel quality is bad, and not all transmission errors can be corrected, the receiver will detect this situation using the error-detection code, then the received coded data block is discarded and a retransmission is requested by the receiver, similar to standard ARQ. In contrary, HARQ II does not discard erroneous received packets and the retransmission contains incremental redundant bits. The receiver then combines these redundant bits with bits of the previous transmission resulting in lower code rates.

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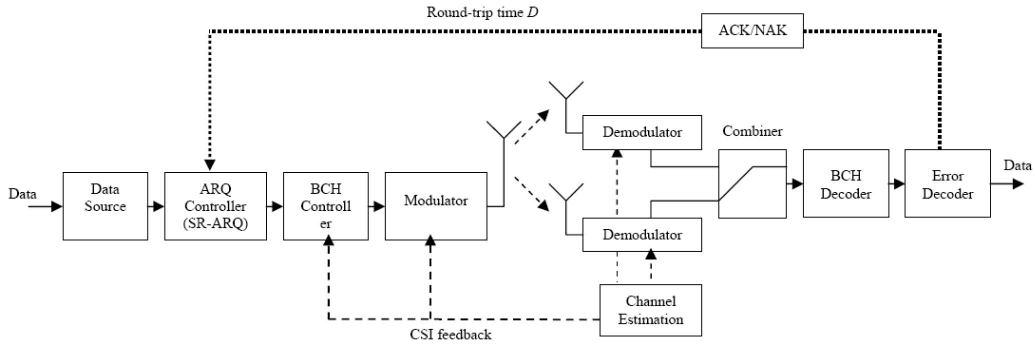


Fig. 1 A block diagram of non-switched dual selection diversity system in the presence of SR-ARQ scheme and BCH channel coding.

Finally, in HARQIII, individually transmitted packets are self-decodable and packets are only combined after decoding has been attempted on each of the individual packets.

If the standard ARQ scheme has to be used over a mobile radio channel, the time-varying multipath fading characteristics introduce a certain amount of correlation between different ARQ packet (re)transmissions; that is, channel errors cannot be assumed to be independent from packet to packet. Therefore, many recent researches [2] [10] [3][7] have dealt with such ARQ schemes in different approaches in order to increase and enhance the system throughput (quality of service) in several ways (1) by applying adaptive modulation format and coding (AMC) [11], or (2) by varying the packet size [10] (3) by adapting packet size in the dual branch diversity receiver [12] or (4) by controlling, for example, the throughput efficiency over multipath block fading channels when having a perfect knowledge of the complex path gains [9].

On the other hand, diversity technique is also a powerful tool in wireless communication systems used to mitigate fading effects [6]. The depth of the fades and/or the fade duration is reduced by supplying the receiver with multiple replicas of transmitted signal that have passed over independently fading channels [13] [14]. In general, there are three common types of linear diversity combining MRC, EGC, and SC normally employed in digital receivers over multipath fading channels. Selection Combining (SC) is the least complicated one since it processes only one of the diversity branches. Specifically, the combiner chooses the branch with the highest signal-to-noise ratio (SNR) or equivalently with strongest signal assuming equal noise power among the branches, however, in a practical system; the diversity branches may have unequal average SNR due to different noise figures or feedline lengths. Therefore, it is important to assess the effect of the correlation factor and the unbalance of average SNR (non-identical branches) on the throughput performance of the SC diversity. Many schemes [13] [5] [6] have been proposed to provide significant power gains over existing selection diversity schemes in Rayleigh fading channels. In [15], for example, has introduced that in very slow fading channels, the dual-branch switched diversity scheme at the transmitter also can improve the throughput efficiency of the ARQ protocol significantly. More specifically, the diversity benefit obtained from this scheme can reduce the delay in transmitting the data packet and this will be an attractive goal in many applications such as audio, image and real-time video streaming.

In this paper, we develop a framework to provide efficient bandwidth access (i.e., efficient throughput performance) over the downlink in UMTS network using SR-ARQ scheme (at the radio link) and BCH channel coding at the physical layer in over Rayleigh fading channel. We introduce the dual-branch diversity receiver (a classical dual-branch selection receiver) which is so-called non-switched diversity (NSD). Both spatially uncorrelated and correlated antenna branches are investigated for identical and non-identical channels using HARQ Type I.

II. System Model

Let us consider Fig. 1 as a UMTS communication system based on Downlink Dedicated Channel (DL DCH) [16]. The system model consists of one transmit antenna at Node B and Radio Network Controller (RNC) and two receiver antennas at User Equipment (UE). In order to predict the link behaviour, the transmitter has to be informed of past link errors in the forward link via a CSI feedback of the error status of the received data. In case of the UMTS this is accomplished by the radio link control (RLC) acknowledged mode (AM). From the link error characteristics of the UMTS model, the estimation for future error probability can be predicted. We also assume that perfect CSI is available at the receiver and the channel is time-varying and frequency flat fading. CSI information are sent back to the BCH controller and modulator using an error free CSI feedback, with a CSI sensing delay $\tau << D$ (round-trip delay of positive (ACK) or negative (NACK) acknowledgements at the radio-data link layer); whereas the sensing delay can be artificially reduced by using prediction filters [17]. Fig. 1 presents schematic block diagram of the proposed dual selection diversity system in the presence of the combination of SR-ARQ scheme and BCH channel coding.

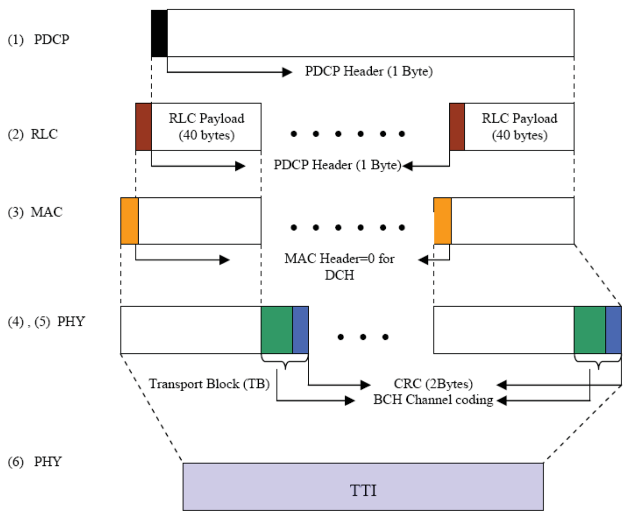


Fig. 2 Packetization for proposed HARQ over UMTS radio interface: 1- PDCP, 2- RLC segmentation, 3- RLC paload and MAC header addition, 4- CRC addition for pure ARQ, 5-Transport Block* concatenation and channel coding (FEC + CRC addition) for HARQ Type I 6- after rate matching and interleaving over one TTI.

*Assume a minimum transport block size equals RLC payload of 320 bits and a maximum equals 511 bits.

A. SC Diversity

At the transmitter, SR-ARQ controller and BCH controller are both considered to provide error protection on the transmitted data depending on the two feedbacks of CSI and ACK/NACK. BCH controller is responsible for adding channel coding to transport block (TB) at the physical layer; and if the BCH decoder at the receiver fails in correcting the bit errors in TB then SR-ARQ controller retransmits the entire transport block (TB) once NACK signal is received. At the receiver, a post-selection combining, i.e., two individual demodulators re associated with each antenna, is considered to be followed by BCH decoder which is used to notify the transmitter with NACK signal if BCH decoding is failed to correct the bit errors. The decision process after the receivers (demodulators) considers a reception as correct using firstly BCH decoding then followed by the error detection using the usual cyclic redundancy check (CRC) bits (as in HARQ I scheme), if it is correctly received over any of the diversity branches. A correct transport block (TB) hence is chosen to the output.

B. RLC/MAC/PHY Models

In Fig. 2, since the PHY layer passes the transport block to the MAC layer together with the error indication from the Cyclic Redundancy Check (CRC) and/or channel coding, the output of the Transmission Time Interval (TTI) in PHY layer can be characterized by the overall probability of transport block error– also called transport block error rate (BLER) in this paper. The smallest TTI is 10 ms which is the same as the radio frame length [16]. For example, PHY model generates a radio frame at a fixed period of 10 ms (for 384 kbps and spread factor (SF) of 8) and 20 ms (for 64 kbps with SF=32) [18]. The RLC entity receives a PDCP PDU which comprises an IP packet of 552 bytes or an ACK of 40 bytes, and additionally PDCP header of 1 byte. This PDCP PDU is segmented into multiple RLC PDUs of fixed sizes. Each of these PDUs fits into a transport block in which a CRC is attached. A typical size of each RLC PDU is 40 bytes, but in our simulation, we choose a typical maximum transport block (TB) size at the PHY layer equals RLC payload plus RLC and CRC headers and overhead parity bits of BCH channel code is no more than 511 bits.

III. Proposed Approach

A. RLC SR- ARQ Throughput

For standard ARQ or hybrid Type-I SR-ARQ with fixed modulation, the throughput efficiency can be defined as [19]

$$\eta_{SR}=\frac{R_C}{T_r}=\left(\frac{L-C}{L}\right)\times(1-p) \tag{1}$$

where *(L-C)/L* denotes the ratio of information bit (RLC payload) to the total bits in a transport block (*L*), *C* is being the CRC bits, and R_C can express the channel code rate. T_r is the average number of transmission attempts per block. Assuming that the ARQ scheme retransmits a packet (block) until the ACK of a successful reception is achieved by $(1-p)$, where p is being a block or packet error rate (BLER or PER). Hence η_{SR} of (1) can be defined as a function of the modulation mode in terms of $p_b(\gamma_b)$ the channel bit error rate (BER), packet length (*L*) in bits including the number of over head bits (e.g., CRC), and received channel SNR per bit (γ_b)[7]

$$\eta_{SR}=\left(\frac{L-C}{L}\right)\left(1-p_b(\gamma_b)\right)^L \tag{2}$$

B. Adaptive RLC

Wireless link throughput is severely affected by channel impairments such as shadowing, multi-path fading, and interference. To solve this problem, two solutions of adaptive link layer techniques can be employed either by adapting the packet length (size) for given average SNR and link layer parameters, to optimize throughput, or via optimizing link layer parameters such as symbol rate and constellation size for fixed packet (block) length for maximal throughput [19]. Indeed, when the packet (block) length is too large, packet error rate (PER) or (BLER) increases, and throughput in consequence is limited by frequent retransmissions. On the other hand, the smaller the packet means the larger the overhead. Hence, the optimal packet length L^* which maximizes the throughput can be derived from (2) as

$$L^*(\gamma_b) = \frac{C}{2} + \frac{1}{2}\sqrt{C^2 - \frac{4C}{\ln(1 - p_b(\gamma_b))}} \tag{3}$$

Using (3) it is noticed that a much smaller block size is more efficient under higher channel BER especially in real-time applications because small blocks have low BLER mean while larger blocks make efficient use of the channel when the channel BER is low.

C. BCH Channel Coding

A channel coding is required for wireless communications to protect data from the errors which may result from noise, fading, and interference. For low SNR region of spread spectrum modulation, where each bit is multiplied by a chip sequence and spread into L bit times, or time division multiplexing, a common idea of *non-extending* a period time of the block can be applied. This does not increase the energy per information bit, and such variation is called namely an *adaptive* FEC.

We now consider a block code BCH FEC with redundancy of parity bits adding to the block, but *without extending* the total block length (L) (in bits) to exceed a maximum length ($L_{\max}$). The block error rate, $BLER_{ec}$, then, with maximum error capacity t can be expressed as [5],

$$BLER_{ec} = 1 - \sum_{i=0}^{t} \binom{L_{\max}}{i} p_b^i \left(1 - p_b\right)^{L_{\max} - i} \tag{4}$$

In our hybrid ARQ scheme, since the error capacity of BCH code is considered to be nine parity bits per error bit for a 511-bits Transport Block (TB), then the maximum throughput (i.e., transmission efficiency) can be calculated as,

$$\eta_{HARQ} = \left(1 - PLR_{BCH}\right) \cdot \left(\frac{L_{ec}}{L_{\max}}\right) \tag{5}$$

where $L_{ec} \equiv L_{\max} - L_{ARQ} - C_{\max}$ denotes the length of encoded block, and $C_{\max} \equiv 9 \times t$ is the length of *inclusive period* of total parity bits per block. Note that $L_{\max}$ does not exceed 511 bits in RLC/PHY layer. For simplicity, we can rewrite (4) as,

$$PLR_{BCH} = 1 - \sum_{i=0}^{t} \binom{511}{i} p_b^i \left(1 - p_b\right)^{511 - i} \tag{6}$$

p_b is the bit error rate defined also in (2) and PLR_{BCH} is the residual block error rate after error-correction at radio link layer. The goal is to obtain t under predetermined p_b for maximal throughput.

IV. THE CHANNELS PERFORMANCE

A. Identical Channels

In SC-NSD combiner based on a BCH SR-ARQ post-reception scheme, the probability of successfully receiving a block after error correction is that of a successful reception over either of the diversity branches, and this can be expressed by

$$P_{ec,1} = 1 - \left(BLER_{ec}\right)^2 \tag{7}$$

And consequently the effective throughput can be computed as,

$$\eta_{SC-NSD,ec} = \left(\frac{L_{ec}}{L_{\max}}\right) P_{ec,1} \tag{8}$$

If the coherent BPSK modulation is used the average bit error probability of correlated Rayleigh fading channel with the average SNR equal to $\bar{\gamma}$ can be expressed in closed form as [14, Eq. 9.268],

$$p_{b,SC} = \frac{1}{(1+\rho)}\left[\frac{1+\rho}{2} - \sqrt{\frac{\bar{\gamma}}{1+\bar{\gamma}}} + \frac{1-\rho}{2}\sqrt{\frac{(1-\rho)\bar{\gamma}}{2+(1-\rho)\bar{\gamma}}}\right] \tag{9}$$

where $\bar{\gamma}$ represents the average SNR of the first branch for equal average branch SNRs ($\bar{\gamma}_1 = \bar{\gamma}_2$), and ρ is the power correlation coefficient between the estimated and actual fadings, and the values of $0 \le |\rho| \le 1$ denotes a measure of the quality of channel estimation in terms of time delay and the maximum Doppler frequency shift (e.g., in land-mobile communication systems). Specifically, the statistical properties of fading signals depend on the field component used by the antenna, the vehicular speed, and the carrier frequency as follows

$$\rho = J_o\left(2\pi f_d T_s\right) \tag{10}$$

J_o is a Bessel function of the zero-*th* order first kind. T_s denotes the symbol time which is less than the coherence time T_c of fading period, i.e. correlation between two symbols over channel in case of slow fading, and the Doppler spread f_d of the signal represents a function of the mobile speed υ and the carrier frequency ($1/\lambda$). Note that the correlation properties of the fading process depend only on $f_d T_s$. When $f_d T_s$ is small (e.g., < 0.1), the process is much correlated ("slow" fading); on the other hand, for large values of

$f_d T_s$ (e.g., > 0.5), successive samples of the channel are almost independent ("fast fading"). For high data rates (i.e., small T_s), the fading process can typically be considered as slowly varying, at least for the usual values of the carrier frequency (900-1800 MHz) or (2 GHz) and for typical mobile speeds.

B. Non- Identical Channels

The unbalance in the average branch SNR in the SC-NSD scheme modeled in Fig. 1a effectively leads to lower the overall throughput performance. The average BER of the coherent BPSK can be written as [14, Eq. 9.265, Fig 9.34]

$$p_{b,Non\text{-}SCl} = \frac{1}{2}\left[1 - \sum_{i=1}^{3} \beta_i \sqrt{\frac{\overline{\gamma}}{1+\overline{\gamma}}}\right], \quad \rho = 0 \qquad (14)$$

where $\beta_1 = \beta_2 = 1$ and $\beta_3 = -1$. For $\rho \neq 0$, $p_{b,Non\text{-}SC}$ can also be numerically computed using (Eq. 9.66) in [14] to evaluate the effect of correlation coefficient and the unequal average SNR in the dual branch SC-NSD combiner (Fig. 1a).

V. Numerical Results

In this section, we focus on average SNR of identical and non-identical branches, and the redundant amount of BCH channel coding for the achievable maximal throughput. The channel model used in the simulations of the throughput performance is a flat Rayleigh fading channel. As a reference, we conducted the numerical results using a typical set of parameters as: the width of the Doppler spectrum, which is determined by the carrier frequency 2GHz and the vehicular speed *v*, the number of the CRC parity bits is 16 at the data-link layer, and the (raw) or reference bit rate at the physical layer is 64kbit/s as in Dedicated channel – DCH UMTS standards. We set the maximum packet size $L_{\max}$ to be no greater than 511 bit for both the optimal throughput without BCH coding and the maximal throughput under various values of BCH code that can be added to the RLC PDU (payload). BLER is assumed independent for the BPSK coherent demodulation scheme.

A. Performance Evaluation

In this study, we evaluate the throughput of HARQ Type I in the two types of diversity schemes described in Section II. The results are conducted using Matlab programming to verify the system performance for correlated and uncorrelated branches when balance and unbalance of average channel SNR are considered in SC scheme. We first consider a fixed small packet size of 511 bit including 16 CRC bit. To provide highest performance, the optimal throughput versus the corresponding optimal average SNR is illustrated in Fig. 3.

Achieving $L^*(\gamma_b)$ in (3) and setting the upper bound of block length to 511 bits in the region of higher values of SNRs, the

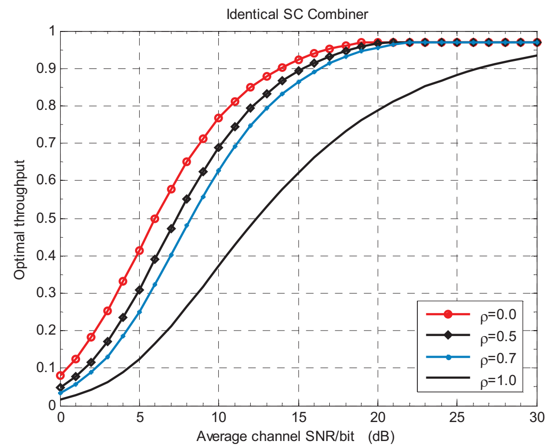


Fig. 3 Comparison of optimal system performance over Rayleigh fading channel. Assume $L_{\max}$ = 511 bits, CRC-16, and no channel coding.

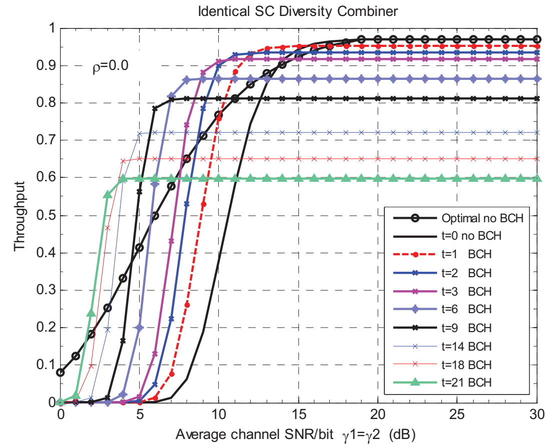
optimal performance in terms of the corresponding bit error rate can be simply evaluated. It is found that there exists a significant channel gain which leads to the maximum upper throughput in particular when correlation factor of the later scheme tends to be 0.0 or less 0.5. In this case, throughput outcomes nearly 20%-40% channel gain compared to the case of ρ equals 1.0. It means that the power correlation coefficient will effectively degrade the system efficiency as far as this coefficient tends to be close to 1.

Fig. 4 reveals the effect of BCH channel coding on the throughput performance in the identical branches of SC diversity receiver for uncorrelated and correlated channels. HARQ Type I scheme illustrates various error-correction bits required for three values of correlation coefficient (ρ) of 0, 0.5 and 1.0. The results compare the optimal throughput (at optimal block size and no BCH) and the non-optimal throughputs obtained at various values of error-correction conditions of BCH code. It is shown two findings: (*i*) optimal throughput outperforms non-optimal throughput of the various error-correction bits in the lower range of channel SNR nearly below 5 (dB); and this throughout can gradually achieve the higher level up to 0.968 at the higher values of SNR. On the other hand, for uncorrelated channel (Fig. 4a) the maximal throughput of a Hybrid ARQ scheme can be observed when error-correction bits equal 9 in order to improve the achievable throughput at the lower range of SNR values (3dB-6dB), i.e., higher bit error rates. Then throughput beyond this range will be constant at 80%. Moreover, the correlation coefficient (Fig. 4b and Fig.4 c) degrades the throughput compared to the uncorrelated channel in Fig. 4a. It is also noticed in all three figures that there is a clear degradation in the maximal throughput of HARQ compared to the optimal standard ARQ at high SNR region. This is due to the redundancy of parity bits which are added to the RLC payload block *without extending* the total block length to exceed a maximum length ($L_{\max}$), explained in Section III. As a result, we conclude that the proposed BCH scheme eventually does not introduce any extra improvement in the throughput performance due to the channel coding overhead (redundancy code) especially in the high SNR regions. Moreover, for low SNR regions we need to provide BCH parity bits to be not exceed 189 bits to maintain the validity of our proposed BCH scheme (i.e., to not exceed a minimum RLC payload size of 320 bits in Fig. 2).

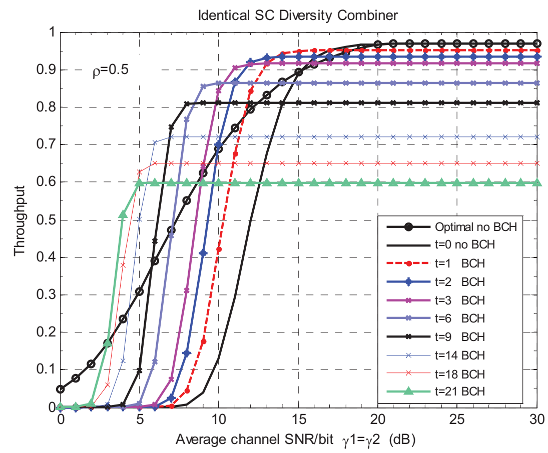
On the other hand, Fig. 5 illustrates the effect of two factors: (1) the unbalance of the average SNR in a dual-branch of SC-NSD combiner, and (2) the correlation coefficient (ρ) on the throughput performance in pure SR-ARQ and in proposed HARQ I based BCH coding. When $\bar{\gamma}_1 = 10\bar{\gamma}_2$ and the correlation increases, a significant degradation in the system performance is observed. In both ARQs, uncorrelated channels outperform the correlated ones of ρ equals 0.5. Specifically, throughput of a HARQ I based BCH attains to be nearly constant (nearly 80%) for the higher range of SNR compared to optimal throughput of pure SR-ARQ scheme.

Fig. 6 explains a performance comparison between a pure (standard) SR-ARQ scheme and a proposed HARQ Type I in identical branches of SC for a predefined average channel SNR of 10 dB. It is clearly shown a significant effect of BCH channel coding on the system throughput versus the client mobile speed. The improvement in throughput performance increases rapidly to achieve 72% once BCH code is increased using proposed HARQ scheme compared to optimal throughput of a pure ARQ, and then it can correct 14 error bits of the original RLC payload. Note that the original size of RLC payload must be no less than 320 bits in our simulations. In contrary, a constant throughput is also observed over the range of user mobility (0km/h-200km/h) or the normalized Doppler frequency ($f_d T_s$ is no greater than 0.0058 or $f_d = 370$ Hz) over Rayleigh fading channel. The reason is that ρ becomes very close to 0.997 or 1.0 according to our system settings.

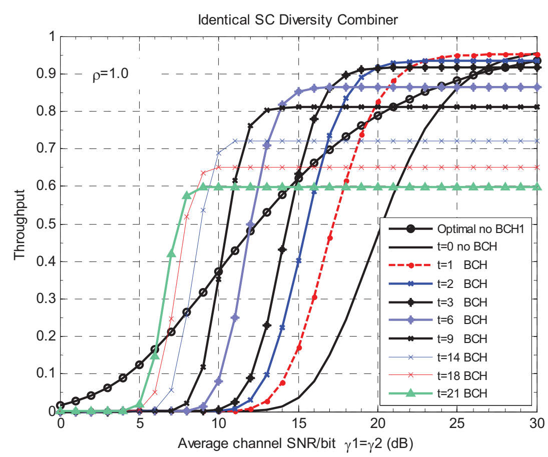
Fig. 7 displays a comparison example of maximal throughput performance versus mobile speed for two different values of average channel SNR of 15 dB and 20 dB in identical branches of SC combiner. The maximal throughput (85%-97%) can be achieved at different conditions of system settings. A higher SNR means a lower BCH coding required, and consequently, no need for channel coding when average SNR achieves 30 dB. However, a high BLER (BER) over a fading channel leads a few parity bits redundancy of channel coding required to be added to the original RLC payload to correct only 2 error bits when SNR equals 20 dBs (Fig. 8 b); and when SNR is 15 dB the BCH parity equals six times of nine PBs to achieve a maximal throughput of 92% (Fig. 8a).



(a)



(b)



(c)

Fig. 4 Throughput vs. average SNR for various values of correlation coefficient and error-correction bits of BCH coding. Assume $L_{\max}$ = 511 bits, CRC-16 in identical branches of SC scheme.

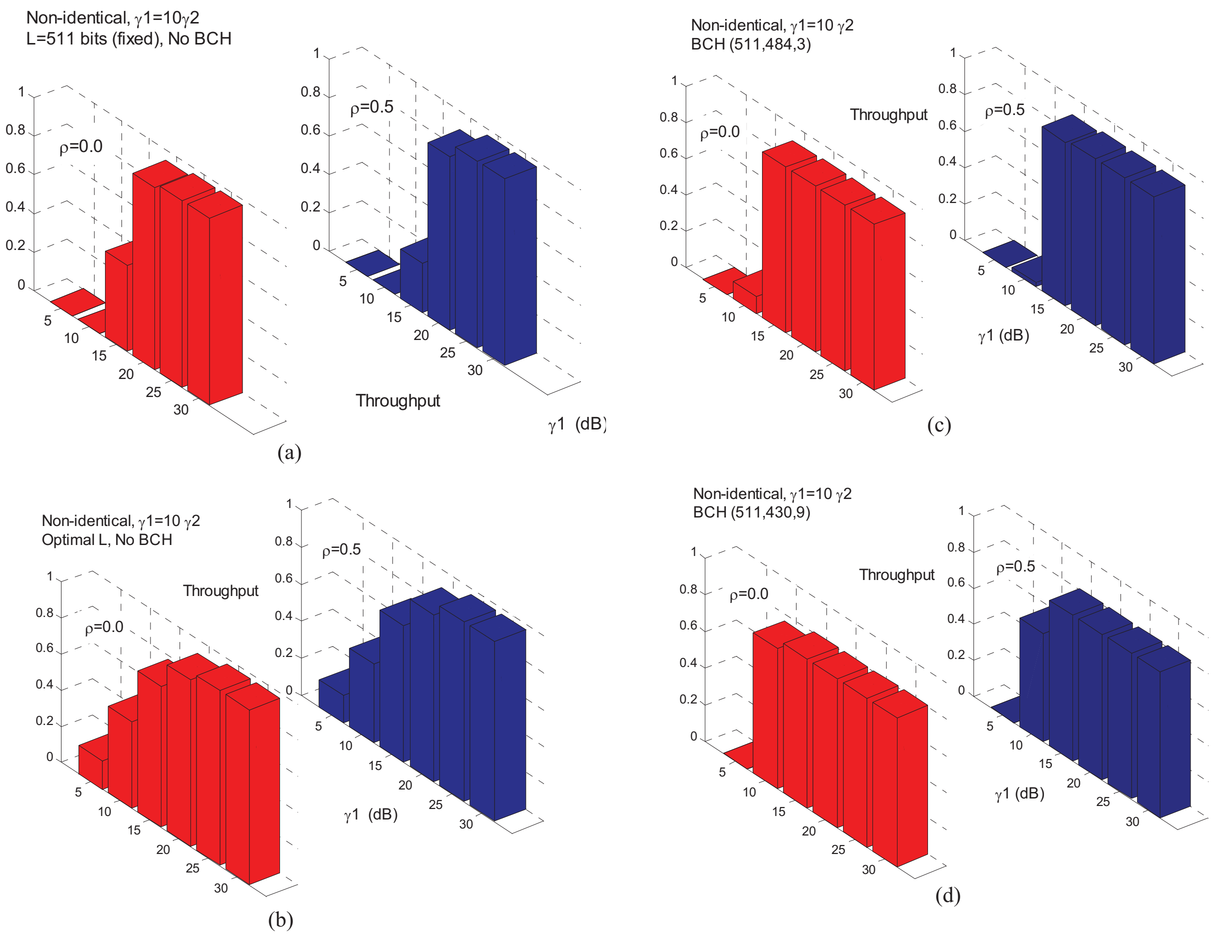


Fig. 5 Throughput vs. the average channel SNR of uncorrelated and correlated branch of SC scheme based HARQ Type I with non-identical branches $\overline{\gamma_1} = 10\overline{\gamma_2}$. (a), (b) Pure SR-ARQ with fixed block and with optimal block size and (c) (d) HARQ with BCH (511,484,3) and BCH (511,430,9).

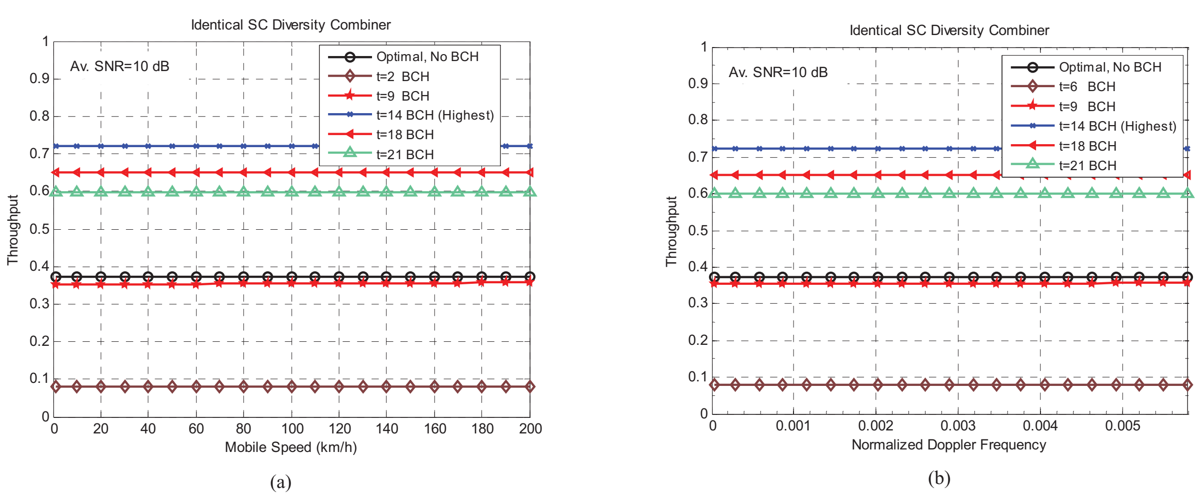
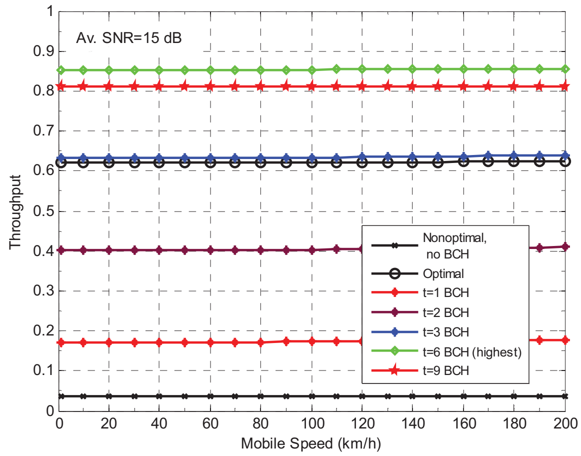
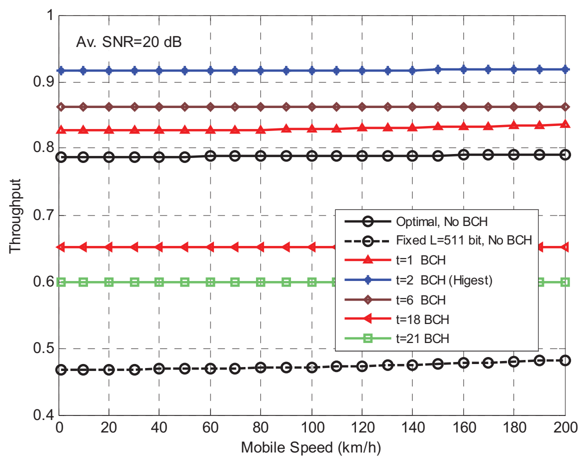


Fig. 6 Throughput of SC scheme based pure ARQ and HARQ Type I with identical branches over Rayleigh fading channel. (a) Mobile speed and (b) Normalized Doppler frequency.



(a)



(b)

Fig.7 Throughput of pure ARQ and HARQ Type I in identical branches over Rayleigh fading channel. (a) Average SNR=15 (dB), and (b) Average SNR=20 (dB).

As a result, it is noticed that an increase in predefined average SNR values (Fig.6 and Fig. 7) will provide a significant improvement in the throughput performance to achieve a maximal value using standard SR-ARQ scheme or under different BCH channel coding using HARQ Type I scheme. Each average SNR gives a certain throughput under a specific channel coding condition (Fig .4c).

VI. CONCLUSION

In this paper, we have studied the performance of standard SR-ARQ and a proposed HARQ Type I based BCH channel coding to evaluate throughput efficiency of dual-branch no-switched selection diversity receivers with both identical and non-identical branches when Rayleigh fading channels are present. The results show that the maximal throughput of HARQ using a combination of SR-ARQ and BCH channel coding at the radio link layer outperforms the optimal throughput of pure SR-ARQ for low channel SNRs. Moreover, correlation coefficient and unbalance of average SNR introduce a significant degradation in throughput performance compared to the balance of SNR in identical branches.

REFERENCES

[1] H. Holma and A. Toskala, *WCDMA for UMTS, Radio Access For Third Generation Mobile Communications*, John Wiley & Sons, Ltd., 2004.

[2] J. Xiao, J. Qiu, and S. Cheno, “A Joint Adaptive Packet Size and Modulation Scheme Combined with SR-ARQ over Correlated Fading Channels”, IEEE 2005, pp. 458-462, 2005.

[3] J. Yun, “Throughput Analysis of Selective Repeat ARQ Combined with Adaptive Modulation for Fading Channels,” *IEEE MILCOM 2002 Proc.*, vol. 1, pp. 710-714, 2002.

[4] J. Roman, F. Berens, M. Kirsch, S. Tanrikulu, “Hybrid ARQ Schemes for Future Wireless Systems based on MC-CDMA,” 2003.

[5] S. S. Chakraborty, M. Liinaharja and K. Ruttik, “Diversity and packet combining in Rayleigh fading channels,” IEE *Proc. Commun, vol. 152, no.3,* pp. 353-356, June 2005.

[6] X. Cai and G. B. Giannakis, “Performance Analysis of Combined Transmit Selection Diversity and Receive Generalized Selection Combining in Rayleigh Fading Channels,” *IEEE Trans on Wireless Commun.*, 2004.

[7] E. Cianca, A. D. Luise, M Ruggieri, and R. Prasad, “Channel-Adaptive Techniques in Wireless Communications: An Overview.” *Wireless Commun. Mob. Compu.*, 2:799-813, 2002.

[8] T. Wang, H. Fang, and L. Chen, “Low-Delay and Error-Robust Wireless Video Transmission for Video Communications,” IEEE Trans. on Circuits and Systems for Video Technology, vol. 12, no.12, pp. 1049-1058, Dec. 2002.

[9] M. W. El Bahri, H. Boujemaa, and M. Siala, “Performance of Hybrid ARQ Schemes over Multipath Block Fading Channels,” Proc. 3rd Inter. Conf. : Sciences of Electronic, Tech. of Infor. And Tele., SETIT2005, March 27-31, 2005.

[10] W. Junli, H. Xiaolin, Y. Changchum and Y. Guangxin, “Variable Packet Size Adaptive Modulation SR-ARQ Scheme for Rayleigh Fading Channels,” IEEE 2004, pp. 1283-1286, 2004.

[11] B. Holter and G. E. Oien, “Performance Analysis of a Rate-Adaptive Dual-Branch Switched Diversity System,” IEEE on Trans. on Commun., vol. 56, no. 12, pp. 1998-2001, Dec. 2008.

[12] G. AL-Suhail, T. Lamahewa, and R. Kennedy, “ Performance of Dual-Branch Diversity Receiver based SR-ARQ in Rayleigh Fading Channel,” IEEE 3rd ICSPCS 2009, Omaha, Nebraska, USA, 2009.

[13] Y. G. Kim and S. Wu Kim, “Optimal Selection Combining for M-ary Signals in Frequency-Nonselective Fading Channels,” *IEEE Trans. on Commun*., vol. 53, no. 1, pp. 84-93, Jan. 2005.

[14] M. K. Simon and M.-S. Alouini, *Digital Communication over Fading Channels*, 2nd edition, J. Wiley, New Jersey, 2005.

[15] K. Weerackody and W. Zeng, “ARQ Scheme with Switched Antenna Diversity and their Applications in JPEG Image Transmission,” Proc. Globcom’95, pp. 1915-1919, Nov. 1995.

[16] A. Lo, G. Heijenk, and C. Bruma, “Performance of TCP over UMTS Common and Dedicated Channels,” Proc. IST Mobile & Wireless Comm. Summit 2003, 15-18Jun 2003, Aveiro, Portugal, pp. 138-142.

[17] G. Femenias, “SR-ARQ for Adaptive Modulation Systems Combined with Selection Transmit Diversity,” *IEEE Trans. On Commun.*, vol. 53, no. 6, pp. 998-1006, June 2005.

[18] W. Karner, O. Nemethova, M. Rupp ,”Link Error Analysis and Modeling for Video Streaming Cross-Layer Design in Mobile Communication Networks,” ETRI Journal, Vol. 29, No. 5, pp. 569-595, Oct. 2007.

[19] T. Yoo, R. J. Lavery, A. Goldsmith and D. J. Goodman, “Throughput Optimization Using Adaptive Techniques,” *Tech Report*, 2004.