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Full-Band CQI Feedback by Huffman Compression in 3GPP LTE Systems

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ABSTRACT

3GPP LTE system exhibits a vital feature of Frequency Selective Scheduling(FSS). Frequency scheduling relies on Channel Quality Indicator(CQI) report by the user equipment (UE). The main challenge in CQI reporting consists of reduction in number of reporting bits maintaining the performance of the system. This paper recommends a new CQI reporting approach which uses Huffman compression for reduction of overhead bits for full-band CQI report. Full-band feedback technique transmits entire CQI report instead of reporting limited bands as done in Best-M reporting techniques. The constraint of Huffman coding that the coding table must be known to both transmitter and receiver prior to transmission, is efficiently explored in this technique. Results indicate appreciable reduction in feedback bits as compared to uncompressed full-band reports. Also, full-band Huffman feedback technique shows profound rise in throughput of the system over sub-band feedback techniques.

General Terms

Wireless communication.

Keywords

Huffman compression, 3GPP LTE CQI, LTE uplink feedback.

1. INTRODUCTION

3GPP Long Term Evolution (LTE) system exploits OFDMA as air interface for improved spectrum management [1]. OFDMA grants downlink transmission for different users on different frequency channels at the same time. Accordingly, need of frequency scheduling at eNodeB(base station) arises. In order to accomplish this type of scheduling, eNodeB demands channel quality information from every user.

Channel information inherently depends on user's received signal quality. Channel Quality Indicator(CQI), an integer value, maps effective SINR [2] for each group of subcarriers known as sub-band. Apart from SINR, this mapping could also deal with multipath delay spread [3]. Link adaptation algorithms have also been investigated for appropriate CQI value selection [4]. E-NodeB transmits pilot (reference) signals at proper intervals for CQI measurement. UE then sends back CQI to its corresponding eNodeB, beneficial for frequency scheduling [5].

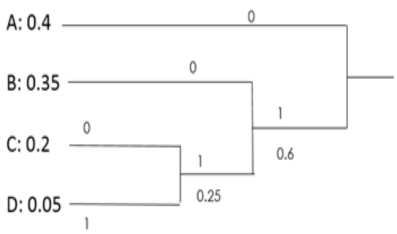
CQI feedback leads to vast utilization of uplink resources. CQI feedback information being the control information, must use minimum possible bits. Use of lower number of bits which could be achieved by feedback of partial information, leads to declination of average throughput of the system. A balance has to be struck between overhead bits and throughput of the system.

Considerable research has been done to come up with a viable CQI reporting technique. CQI reporting techniques could be roughly classified as full-band and sub-band feedback techniques [6]. Full-band feedback uses compression methods with quality report for entire bandwidth. DCT and Haar compression based methods have been designed for the same [7]-[9]. Sub-band feedback reports limited number of bands corresponding to best channel quality[10]-[13]. Such technique improves overhead, weakening the throughput of the system [14].

This paper concentrates on application of variable length coding for overhead reduction of full-band feedback technique. Huffman compression is an efficient variable length coding technique which works on probability of occurrence of symbols to be encoded. Since Huffman compression is applied on full band reports, it provides throughput similar to that of uncompressed full-band reports. Paper structure is as follows: Sec 2 throws light upon basic Huffman compression. Full band Huffman compression scheme is explained thoroughly in Sec.3. Overhead and performance analysis for the scheme is presented in Sec 4. The work is concluded in Sec 5.

2. HUFFMAN COMPRESSION

Huffman coding allows accurate retrieval of original data from compressed data. Variable number of bits are assigned in such a way that symbols with higher probability of occurrence are assigned lower number of bits and vice-versa. A fascinating property of Huffman compression is that generated symbol code forms a prefix code. No code word is prefix of any other code word in a prefix code. This facilitates accurate decoding of data from compressed data, by making use of coding table that was used for encoding. Huffman code formation for 4 symbols with probabilities {0.4,0.35,0.2,0.05} is shown.



A	0
B	10
C	110
D	111

Symbols are arranged in descending order of their probabilities. Lower two probabilities are added up and resulting sum along with remaining probabilities are again arranged in descending order. This process is continued until only two probabilities are left out. At every stage 0 and 1 are assigned to the probabilities which are added. Symbols are then traced from last to first stage to get Huffman code. Huffman code for above case is shown in table. As observed, no code word is prefix of other code word.

3. FULL BAND HUFFMAN CQI FEEDBACK SCHEME

The basic idea is to assign minimum no. of bits to CQI values occurring the most & maximum no. of bits to CQI values occurring the least, thereby reducing the overall CQI feedback overhead. Number of occurrence for each CQI value could be counted & number of bits to be assigned to each value could be decided. However, Huffman coding has a constraint that receiver must know the coding table used at the transmitter for decoding purpose. Hence coding table used needs to be transmitted to receiver. But this would lead to unacceptable overhead. Thus assignment of bits dynamically is not possible & a static scheme has to be developed.

This static scheme assumes that CQI values from a particular range occur more number of times in the current CQI report, compared to other values. Values in this range are then assigned least number of bits. Keeping this in mind, Huffman code for all CQI values could be generated. CQI range (1 to 15) is divided into groups where occurrence of each group in CQI report is assumed to be different. Group A values are assumed to occur the most & hence assigned least no. of bits. Descending order of occurrence of groups is:

Group A > Group B > Group C > Group D & so on.

Scheme uses one of the possible group formation. Possible group formations are shown.

Table 1.Huffman Code for 2 groups

Group	Huffman Code
A	[0,0,0]
	[1,1,0]
	[0,1,1]
	[0,1,0]
	[1,0,1]
	[1,0,0]
	[0,0,1]
B	[1,1,1,1,0,1]
	[1,1,1,1,0,0]
	[1,1,1,1,1,1]
	[1,1,1,1,1,0]
	[1,1,1,0,0,1]
	[1,1,1,0,0,0]
	[1,1,1,0,1,1]
	[1,1,1,0,1,0]

Table 2.Huffman Code for 3 groups

Group	Huffman Code
A	[1,0,1]
	[1,0,0]
	[1,1,1]
	[1,1,0]
	[0,0,1]
B	[0,1,0,1]
	[0,1,0,0]
	[0,1,1,1]
	[0,1,1,0]
	[0,0,0,1]
C	[0,0,0,0,1,1]
	[0,0,0,0,1,0]
	[0,0,0,0,0,0,1]
	[0,0,0,0,0,0,0]
	[0,0,0,0,0,1]

Table 3.Huffman Code for 4 groups

Group	Huffman Code
A	[1,1]
	[1,0]
	[0,1]
B	[0,0,1,1]
	[0,0,0,0,0]
	[0,0,0,1,0]
	[0,0,0,0,1]
C	[0,0,1,0,0,1]
	[0,0,1,0,0,0]
	[0,0,1,0,1,1]
	[0,0,1,0,1,0]
D	[0,0,0,1,1,0,1]
	[0,0,0,1,1,0,0]
	[0,0,0,1,1,1,1]
	[0,0,0,1,1,1,0]

Table 4. CQI Grouping for each code table

No. of groups	No. of code tables	CQI grouping for each code table	Comments
2	2	Code 1: A (1 - 7),	Group with minimum bits

		B (8 – 15) Code 2: A (8 – 15), B (1 – 7)	per CQI value is group A. Group with maximum bits per CQI value is group B.
3	6	Code 1: A (1 – 5), B (6 – 10), C (11 – 15) Code 2: A (1 – 5), B (11 – 15), C (6 – 10) Code 3:A(6 – 10),B (1 – 5),C(11 – 15) Code 4:A (6 – 10), B(11 – 15),C (1 – 5) Code 5: A (11 – 15), B (1 – 5), C (6 – 10) Code 6: A (11 – 15), B (6 – 10), C (1 – 5)	Group with minimum bits per CQI value is group A. Group with maximum bits per CQI value is group C.
4,5…… …..15	4!,5!.. ….15!	‘’4!,5!……….15!’’ combinations of “4,5…………15’’ groups respectively	Group with minimum bits per CQI value is group A. Group with maximum bits per CQI value is last group.

Formation of code tables is done prior to transmission of CQI values. One of the above combination is used.

The steps to be carried out for this scheme could be summarized as follows:

1. Divide CQI value range (1 to 15) into groups. Min. 2 groups & max. 15.
2. Form Huffman code tables for the decided group formation.
3. Get the CQI values for all active sub-bands (full-band CQI report).
4. Count the number of occurrence for individual CQI values within each group.
5. Add & obtain the total occurrence number for each group.
6. Arrange groups in descending order of total occurrence number.
7. Select relevant code table from available code tables. Group with maximum occurrence is group A & subsequent groups in descending order of occurrence number.

For example, consider following CQI vector and scheme with 2 groups:

CQI	12	12	4	10	5	8	8	7	4	5

Count for group 1 to 8 : 7, Count for group 9 to 15 : 3. Higher count group is the first group and hence group A is from 1 to 8 and group B from 9 to 15. Hence, Code 1 is selected. Thus, range of values with more count are assigned less number of bits.

Key Points:

1. CQI values within a particular group are considered to be with equal probability of occurrence. Hence, roughly same number of bits are assigned to individual values within a group.
2. More number of groups allows to assign lesser number of bits per value.
3. The decision of number of groups and formation of code tables should be done prior to CQI computation.
4. A particular group is not distributed over CQI value range. A set of consecutive CQI values is considered to be a group (such as 1 to 8 and 9 to 15).
5. Better compression is possible if reported CQI values are concentrated in a single group (particularly Group A). For this case, more number of groups is feasible. However if CQI values are distributed in entire CQI range then it is better to have lesser number of groups.

4. OVERHEAD & PERFORMANCE ANALYSIS

4.1 Overhead Analysis

Compression depends on occurrence of CQI values. The analysis is shown for system with 25 sub-bands. Hence maximum occurrence of values in group A could be 25 which corresponds to maximum compression. Similarly, min. occurrence of values in group A will result in minimum compression. For example, consider scheme with 2 groups :

Occurrence number for group A $\geq$ Occurrence number for group B

1. Distribution of 25 values: 13 in group A and 12 in group B

$$\text{Total bits required(min. compression)} = (13 \times 3) + (12 \times 6) = 111\text{bits}$$

2. Distribution of 25 values: 25 in group A and 0 in group B

$$\text{Total bits required (max. compression)} = (25 \times 3) = 75 \text{ bits}$$

Same analysis could be extended to schemes with higher groups.

(For a single group with variable length of bits for individual values, max. number of bits for single value is considered)

Table 5.Compression for different number of groups

Full band with Huffman compression			Full band feedback without compression
Number of Groups	**Total bits in minimum compression**	**Total bits in maximum compression**	
2	111 bits (A/B : 13/12)	75 bits (A/B : 25/0)	125 bits
3	115 bits (A/B/C : 9/8/7)	75 bits (A/B/C : 25/0/0)	
4	122 bits (A/B/C/D : 7/6/6/6)	50 bits (A/B/C/D : 25/0/0/0)	

Table 6.Overhead comparison with sub-band methods

Feedback Scheme	Bit Computation Formula	Total bits required $N_{sb} = 25$, $M = 7$
Full feedback without compression	$5 \times N_{sb}$	125 bits
Full feedback Huffman with 4 groups	Max. compression: $N_{sb} \times 2$	50 bits
Best-M individual	$5 \times M + \left\lceil \log_2 \binom{N_{sb}}{M} \right\rceil + 5$	59 bits
DCT significant-M	$5 \times M + \left\lceil \log_2 \binom{N_{sb} - 1}{M - 1} \right\rceil$	53 bits
DCT partitioning	$5 \times (N_1 + N_2) + \left\lceil \log_2 \binom{N_{sb}}{M} + \log_2 \binom{M-1}{N_1 - 1} + \log_2 \binom{N_{sb} - M - 1}{N_2 - 1} \right\rceil$	$N_1 = 6$, $N_2 = 1$ 57 bits

As seen from table 5, maximum compression of up-to 50 bits is possible for scheme with 4 groups. Huffman scheme results in bit saving of 11.2% to 40% for 2 groups, 8% to 40% for 3 groups, 2.4% to 60% for 4 groups.

More maximum compression is possible for schemes with higher number of groups.

As seen from table 6, scheme with 4 groups outperforms Best M individual and DCT based schemes for M=7.

4.2 Performance Analysis

Simulation results for comparison of throughput for different feedback techniques, considering various parameters are presented in this section.

Table 7.Simulation parameters

Parameters	Values
System bandwidth	10 MHz
RB bandwidth	180 kHz
Carrier frequency	2 GHz
Scheduler	Proportional Fair
Number of TX antennas	1
Number of Rx antennas	2
Channel model	Pedestrian B
UE speed	3 km/h, 15km/h
CQI feedback delay	2 TTIs
FFT size	1024
Number of sub-carriers	600
Target BLER	10%

It was evident from the simulation results that full-band Huffman scheme produced better throughput over sub-band schemes such as Best-M individual and DCT based schemes. Higher throughput for full-band scheme was obvious as it reported entire CQI thereby providing more precise information to base station as compared to sub-band schemes.

Simulation was carried out for UE speed’s of 3km/h & 15km/h.

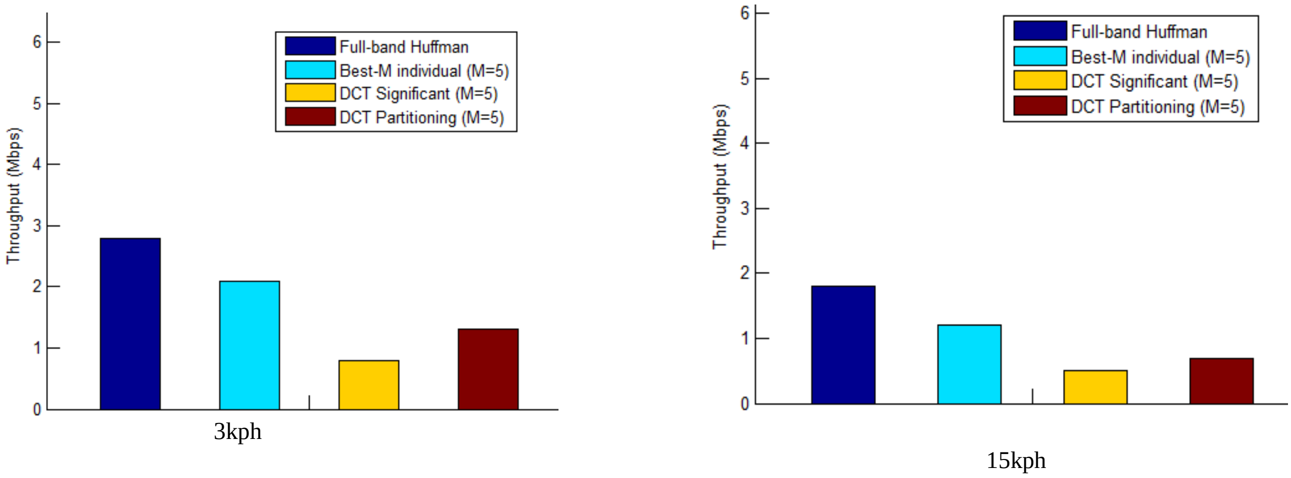


Figure 1. Throughput comparison for 3kph & 15kph UE speed's

5. CONCLUSIONS

This paper proposes Huffman compression for full-band CQI feedback in LTE systems. The proposed scheme results in considerable bit saving for full-band reports. Proper grouping of CQI values followed by occurrence of full-band values over these groups forms the basis for this scheme. Scheme allows compression to such an extent that it even outperforms some of the sub-band feedback schemes. This scheme reports full-band values thereby providing better throughput over all other feedback schemes. Huffman compression thus achieves perfect balance between overhead reduction and throughput requirements.

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