Coverage Enhancement of PBCH using Reduced Search Viterbi for MTC in LTE-Advanced Networks

Parthiban Annamalai*, Sajal Kumar Das*, Jyotsna Bapat† and Debabrata Das†
*Ericsson, Bangalore, India
Email: {parthiban.annamalai & sajal.kumar.das}@ericsson.com
†IIIT Bangalore, India
Email: {jbapat & ddas}@iiitb.ac.in

***Abstract*—Machine Type Communication (MTC) is becoming an integral part of the Long Term Evolution - Advanced (LTE-A) cellular network. Challenges arise when some of the MTC devices, due to the nature of their applications, are deployed in low signal locations. As per 3GPP requirements, there is a need for additional coverage enhancement up to 20 dB in comparison with *LTE category 1* UE for MTC devices. In the previous works reported till now, *Repetition Coding* is proposed as an effective technique to achieve the required coverage enhancements at cost of longer decoding time. In low signal conditions where many repetitions are required to build the SNR needed, the decoding delay may be unacceptable. For a LTE-A MTC UE, Physical Broadcast CHannel (PBCH) decoding has a very important role and fast, efficient decoding of PBCH will help to improve the device performance. In this paper, we propose to use well established technique called Reduced Search (RS) Viterbi to improve PBCH decoding performance without compromising the time-to-decode. RS Viterbi technique utilizes *a priori* knowledge of transmitted bits to reduce the size and complexity of trellis, which in turn also reduces probability of choosing incorrect path, i.e., error. Up to 2.2 dB SNR gain is seen in simulation using the RS Viterbi decoding against the conventional Viterbi decoding, which will contribute in improving the sensitivity of MTC devices for better reachability.**

Keywords*—*LTE, UE, MTC, PBCH, Coverage Enhancement.

I. INTRODUCTION

Machine Type Communication (MTC) is considered to be a promising data communication technology that enables ubiquitous connectivity between autonomous devices without or with minimal human interaction for "Internet of Things (IoT)" vision. MTC can be a catalyst for numerous applications impacting our day-to-day life positively. Henceforth, population of MTC devices is expected to grow several orders of magnitude greater than that of Human-to-Human (H2H) communication devices. Hence, MTC (i.e., IoT) is envisaged as a next technology revolution [1].

From the network side, cellular network such as Long Term Evolution - Advance (LTE-A) promises to be potential choice for MTC devices connectivity. This is mainly due to the advantages of better coverage, performance, lower network deployment cost and also operators preferences to minimize the number of RATs (Radio Access Technology) to support. Henceforth, any improvements and/or optimizations planned for MTC are better to be suggested on top of LTE-A for longer sustenance. As per 3GPP discussions [2], there is an additional requirement of 20 dB coverage enhancement for MTC devices. Accordingly, in this paper we focus on a specific problem of coverage enhancement of PBCH in LTE-A system. PBCH carries the Master Information Block (MIB) that consists of parameters essential for initial access to the cell. Early decoding of PBCH by UE even in low signal conditions is important since fast, efficient, right decoding of PBCH will help to improve the device performance in terms of faster cell selection, quicker camping, lower power consumption etc.

Repetition is a simple and efficient method [3]-[8] to improve the coverage enhancement across channels. Repetition coding, while effective, adds considerable delay to the decoding process, especially in low SNR conditions due to multiple repetitions needed to achieve required BER. As an alternative, we propose to use a form of Reduced Search (RS) Viterbi to improve the decoding performance. Many forms of RS Viterbi algorithms have been proposed in literature. Of them, [9] & [10] talk about systematically pruning Trellis by *a priori* knowledge of transmitted bits in decoder to produce optimal results. There is another category of RS Viterbi mostly suited for higher constraint length which reduces the complexity at the cost of increased probability of error and hence produces lower (sub-optimal) performance [11], [12].

In this paper, we propose to use optimal form of RS Viterbi algorithm that efficiently makes use of *a priori* knowledge bits in the transmitted message content. Numbers of paths are reduced systematically with the knowledge of bits available in the received data. Bit error probability is thus reduced since the invalid paths are never considered in the Trellis, which might have been chosen in a poor signal conditions by a conventional Viterbi decoder. It is still an optimal solution since it considers all the valid paths. Importantly, the proposed technique doesnt demand any change in the current network design or specifications. Up to 2.2 dB SNR gain is achieved using the scheme proposed here and it would definitely yield better decoding results for PBCH in poor signal conditions without compromising on the time-to-decode. The approach proposed can be considered as one of the potential solutions for MTC devices mainly from coverage requirements perspective.

This paper is organized as follows: Section II briefs about PBCH coding procedure in LTE. In Section III, RS Viterbi technique is explained and Section IV discusses our contribution i.e., usage of *a priori* known bits in RS Viterbi for LTE PBCH decoding. Section V provides the simulation results and finally, Section VI concludes the proposal.

978-3-9018-8273-9/15/ ©2015 IFIP

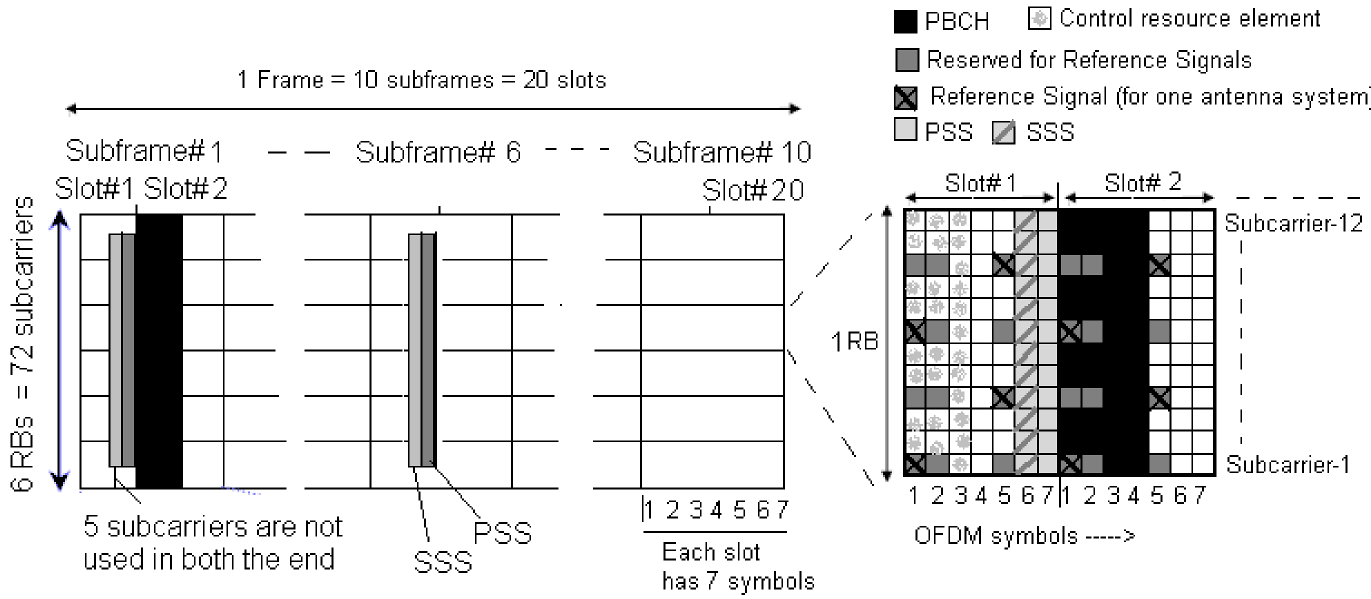

Fig. 1. PBCH Locations in LTE Downlink Resource Blocks

II. PBCH IN LTE

After initial cell synchronization (Primary and Secondary Synchronization Signal reception), UE tries to receive PBCH for getting MIB information, which is required for camping into the system. In typical cellular systems, the basic system information which allows UE to operate and configure other channels is carried by a Broadcast Channel (BCH). In LTE, the BCH is mapped to a physical channel referred to as PBCH, which is transmitted over four sub-frames with 40 ms timing interval. The MIB, which consists of a limited number of the most frequently transmitted parameters essential for initial access to the cell, is carried on the PBCH. The information carried in the MIB is crucial in the initial cell selection process, and consists of:

- DL Bandwidth (3 bits) tells the System bandwidth (1.4MHz to 20 MHz)
- PHICH Configuration (3 bits)
- System Frame Number (8 bits)
- Spare bits (10 bits); [*Set as zeroes by network*]

The BCH data arrives to the coding unit in the form of a maximum of one transport block every transmission time interval (TTI) of 40 ms. Generally there are 14 information bits + 10 spare bits (set to all zeroes currently), makes total 24 bits. From these information bits, 16 CRC parity bits are computed. The eNodeB can use 1, 2 or 4 antennas for transmission. The CRC bits are scrambled based on the 1, 2 or 4 antenna used in the transmitter. So, total number of bits becomes 14 + 10 + 16 = 40 bits. After 1/3 rate convolutional encoder, total number of bits (for normal CP) becomes = 40 $\times$ 3 = 120. Then 24 $\times$ 3 NULLs are appended to these 120 bits to make 192 for sub-block interleaving and inter-column permutations. These bits are repeated 16 times by discarding the appended Nulls, resulting in 120 $\times$ 16 = 1920 bits [13]. These 1920 bits are then QPSK mapped so that the total number of QPSK symbols become = 1920/2 = 960 symbols. These 960 symbols are segmented into 4 equal sized self-decodable units. Then these symbols are placed in PBCH Resource Elements in 2^{nd} slot of 1^{st} sub-frame. That means 1^{st} sub-frame's 2^{nd} slot contains 960/4 = 240 symbols and then inserted in the OFDM time-frequency resource elements (RE) grids [14]. The Physical BCH channel is restricted to the 72 sub carriers around the DC in the resource grid irrespective of the UE bandwidth. The PBCH is transmitted in the first four OFDMA symbols of the 2^{nd} slot of 1^{st} sub-frame in every radio frame as shown in Fig. 1. For example, in a sub-frame which contains PBCH (e.g. 1^{st} sub frame of a frame) there are total 72 $\times$ 7 $\times$ 2 = 1008 REs (for normal CP). Out of that, currently in that sub-frame total number of CRS (Cell Reference Signal) = (4 $\times$ 6) $\times$ 6= 144 REs (for 4 antennas system). If the system is using single antenna instead of 4 antennas, then 48 REs will be having CRSs and the remaining elements (out of 144) will be Null.

III. REDUCED SEARCH VITERBI DECODING

Many forms of Reduced Search Viterbi decoding techniques are available in literature where the intention is to reduce the complexity of the Trellis decoding especially in case of higher order states. But the optimal RS Viterbi technique considered here is proven to improve decoding performance by utilizing *a priori* knowledge of bits available in the received data. It is very common to have some of the fields of the control and/or data blocks are either spare or fixed in standardized communication system. RS Viterbi effectively utilizes this knowledge to limit the trellis search to only valid paths to improve the decoding performance. Additionally, this also helps in reducing computational complexity of Trellis. These improvements are limited by the amount of *a priori* information of the transmitted bits.

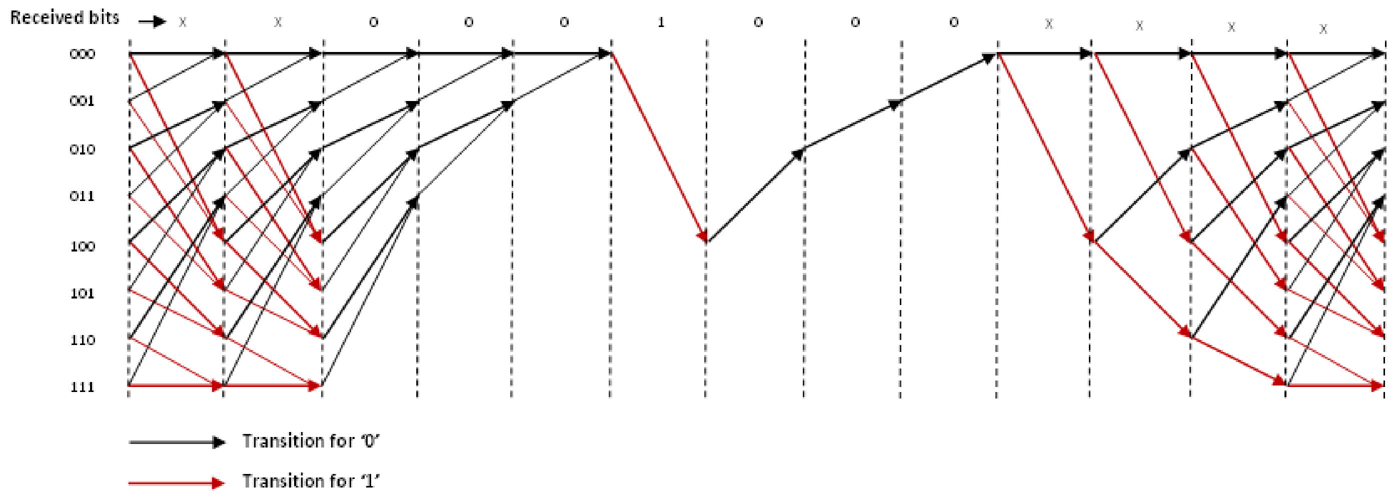

Fig. 2. Concept of Reduced Search (RS) Viterbi with 8-states and 6 *a priori* known bits

TABLE I. COMPUTATIONAL COMPLEXITY OF CONVENTIONAL AND RS VITERBI

S.No	Computational Complexity	Conventional Viterbi	RS Viterbi (From the start of 1^{st} known bit to $((K-1) \times m)$ bits; but before end of known bits	RS Viterbi (After $((K-1) \times m)$ bits from start of known bits till end of known bits	RS Viterbi (From the end of known bits to $((K-1) \times m)$ bits
1	Number of Branch Metrics	$N_1(t) = 2^n \times 2^{(K-1)}$	$N_1(t) = N_1(t-1)/2$	$N_1(t) = 1$	$N_1(t) = N_1(t-1) \times 2$
2	Winning Path Comparisons per State	$N_2(t) = 2^m$	$N_2(t) = 2^m$	$N_2(t) = 1$	$N_2(t) = 1$
3	Number of Winning Path Comparisons and PM Accumulations	$N_3(t) = 2^{(K-1)}$	$N_3(t) = N_3(t-1)/2$	$N_3(t) = 1$	$N_3(t) = N_3(t-1) \times 2$

A. *Technical Description*

In a reliable communication system using convolutional encoder, the receiver should determine the "best possible" sequence of transmitter states to decode the information properly. There are many ways of defining "best", but one that is especially appealing is the most likely sequence of states (i.e., message bits) that must have been traversed by the transmitter. The Viterbi decoder finds such a maximum likelihood path through the Trellis structure. In general, it looks for all possible paths (from state machine) the transmitter would have traversed for different inputs to find the maximum likelihood path. If knowledge about some of bits is available to the receiver, the same can be better utilized to reduce the path search. It will eventually bring down the number of valid paths by restricting the branches to only known inputs. Of course, this approach depends on the Constraint Length (K) and the number of known bits. Also it is important to mention that these known bits need not be continuous to improve the decoding performance. Even chunks of more than one known bit patterns can also be used to get the similar advantages. Accordingly, RS Viterbi decoder will have additional input interface parameters for *a priori* bits and their locations since the implementation is generic.

An example of RS Viterbi and its reduced Trellis structure is shown in Fig. 2 for 8-states and 6 bits of the transmitted message is known to the receiver. It can be observed from Fig. 2 that RS Viterbi effectively utilizes this knowledge of pre-known bits to reduce the Trellis structure. This reduced Trellis structure helps to minimize:

- Number of Path Metric (PM) computations
- Number of states
- Number of Branch Metric (BM) computations and PM accumulations.

B. *Performance Gain*

RS Viterbi decoder able to achieve better performance gain against the conventional Viterbi especially in low SNR conditions by discarding irrelevant states and branches in trellis structure with the knowledge of pre-known bits. This really helps to improve the overall BER. It is important to note that RS Viterbi performance at good SNR is at par with the conventional Viterbi algorithm which is expected. As mentioned earlier, performance gain of RS Viterbi can vary greatly with:

- Constraint Length (K) of Convolutional Encoder
- Number of known or fixed bits knowledge available to the receiver
- Rate of the Convolutional Encoder (m/n)
- Message Length

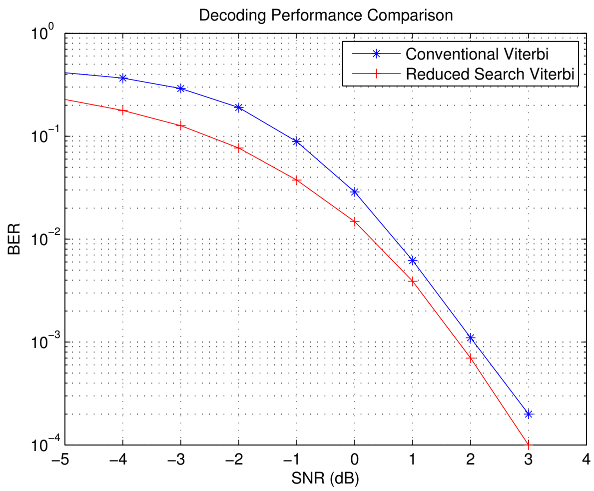

Fig. 3. LTE PBCH Decoding Performance Comparison under AWGN

C. Reduced Complexity

Since only unknown bit combinations are considered in Trellis search, computational complexity can be reduced significantly. Table I compares the computational complexity of conventional and RS Viterbi. In the Trellis structure, reduction in branches and states are possible for the decoding stages corresponding to known bits and also for the stages from the end of known bits till $((K-1)\times m)$ bits. In other stages, computational complexity remains the same as that of the conventional Viterbi.

IV. PROPOSED PBCH DECODING USING RS VITERBI

As mentioned earlier, PBCH decoding performance plays a major role in LTE UE or for any MTC devices because it helps faster cell selection, improved camp on time and also reduced power consumption. The legacy methods available till now take longer time to decode PBCH successfully especially at low SNR. To improve the same, the RS Viterbi method is proposed for PBCH decoding. From [15], it can be seen that 10 spare bits of total 24 bits are set to zeros by the network and the same information is used differently in [16] for enhancing the coverage by optimally searching for the remaining 14 bits. Considering that only *LTE Category 1* UE version is sufficient for MTC devices and there is a very rare possibility of any changes happening to the existing PBCH signaling in standardization, these 10 spare bits will remain unchanged. So, it makes good sense to consider these bits as fixed zeroes and use them as needed in the receiver. During the channel decoding using RS Viterbi, these pre-known bits will be decoded correctly and at the same time it will influence the adjacent bits decision to help them decode properly by choosing the right path. Hence this will also reduce the complexity of the decoding process and at the same time the decoding performance will also improve.

V. SIMULATION RESULTS AND DISCUSSION

MATLAB based LTE simulator is used for the validating the idea proposed. LTE PBCH channel is configured as per the 3GPP mandate with a block size of 40 information bits. Apart from conventional Viterbi decoder available in the receiver chain, RS Viterbi is newly implemented which is made to utilize the 10 zeroes out of 40 bits (24 bits + 16 CRC bits) of PBCH block effectively. Nevertheless, this RS Viterbi is generic enough to trim down the Trellis structure as per the configurations. Compared to regular Viterbi, two extra input interface parameters for RS Viterbi are *a priori* bits and their locations. 10^6 bits are considered for every run using conventional and RS Viterbi. Results presented here are averaged over 10 Monte Carlo simulations. From these simulation results, good improvement in decoding performance gain is seen which is mainly attributed to the longer constraint length of 7 and higher number of pre-known bits. Fig. 3 plots the SNR vs. BER for RS Viterbi against the conventional Viterbi. Maximum SNR gain of 2.2 dB is seen at lower SNRs. At 10% BER (standard for comparison), an improvement of 1.2 dB is observed. In addition to the SNR gain, more than 30% reduction in computational complexity is achieved for RS Viterbi compared to standard Viterbi decoding.

VI. CONCLUSION

In this paper, we have proposed to use an efficient Reduced Search Viterbi technique for improving decoding performance of LTE PBCH. It is a generic technique and can be utilized wherever *a priori* knowledge of some of the transmitted bits is available to the receiver. This approach can be applied to variety of communication systems since most of the standardized systems today use convolutional coding and may have such fixed or known bit fields in their control and/or data blocks. In this paper, a priori knowledge of transmitted bits in the LTE PBCH block is used to reduce the number of trellis search in Viterbi decoding. Systematically removing invalid paths in the trellis reduces both probability of error and computational complexity of algorithm. Results of this scheme are compared against the conventional Viterbi. From simulation results it is seen that RS Viterbi achieved maximum SNR gain of 2.2 dB. This SNR gain will be very helpful in coverage enhancement of PBCH especially in poor signal conditions without compromising on the time-to-decode.

ACKNOWLEDGMENT

The authors want to thank Ericsson for the support provided for this work.

REFERENCES

[1] Geng Wu, Shilpa Talwar, Kertin Johnson, Nageen Himayat, and Kevin D. Johnson, “ M2M: From Mobile to Embedded Internet”, in *IEEE Communications Magazine*, pp. 36-43, April 2011. .

[2] 3rd Generation Partnership Project ,“Study on provision of low-cost Machine-Type Communications (MTC) User Equipments (UEs) based on LTE”, *TR 36.888, V 12.0.0*, June 2013.

[3] “Developing LTE into a ubiquitous wireless WAN for M2M”, *ETSI M2M Workshop 2013*, Sony Europe Limited.

[4] David Astely, Erik Dahlman, Gabor Fodor, Stefan Parkvall, and Joachim Sachs, “LTE Release 12 and Beyond”, in *IEEE Communications Magazine*, pp. 154-160, July 2013.

[5] Joachim Sachs, “Potential of LTE for Machine-to-Machine Communication”, in *Global Design Symposium: Future LTE and network optimization for M2M support*, Tokyo University, Nov 2013.

[6] Joel Berglund, “Extended LTE Coverage For Indoor Machine Type Communication”, in *Thesis from Linkping University*, Sweden, June 2013.

[7] “LTE MTC: Optimizing LTE Advanced for Machine-Type Communications”, Qualcomm, October 2014

[8] “LTE Evolution for Cellular IoT”, Ericsson & NSN, April 2014.

[9] Tae Ryun Chang, *et al.*, “Decoding scheme using A-priori information about transmitted messages”, U.S. Patent 8259866 B2, September 4, 2012.

[10] Anthony Richard Huggett, “Viterbi decoding for convolutional encoded signals with scattering of known bits”, E.P. Patent 1463207 A1, September 29, 2004.

[11] S.J. Simmons and P. Senyshyn, “Reduced-Search Trellis Decoding of Coded Modulations over ISI Channels”, in *IEEE GLOBECOM 1990*, Vol. 1, pp. 393-396, Dec 1990.

[12] Sooyoung Kim and Deock-gil Oh, “Reduced-Search SOVA for block turbo codes”, in *IEEE ICC 2003*, Vol. 5, pp. 3076-3079, May 2003.

[13] 3rd Generation Partnership Project, “Multiplexing and channel coding”, 3GPP Tech. Spec., TS 36.212, V11.5.0, July 2014.

[14] 3rd Generation Partnership Project, “Physical channels and modulation”, 3GPP Tech. Spec., TS 36.211, V11.5.0, Jan 2014.

[15] 3rd Generation Partnership Project, “Radio Resource Control (RRC); Protocol specification”, 3GPP Tech. Spec., TS 36.331, V12.3.0, Sep 2014.

[16] Shin-Lin Shieh, Yu-Chih Chen, “Channel Decoder Design of Physical Broadcast Channel for Coverage Enhancement in LTE”, in *International Journal of Science and Engineering*, Vol.4 No.1, pp. 365-376, 2014.