A Reconfigurable Filter Bank for Uniform and Non-uniform Channelization in Multi-Standard Wireless Communication Receivers

S. J. Darak, A. P. Vinod, R. Mahesh

School of Computer Engineering,
Nanyang Technological University,
Nanyang Avenue, Singapore – 639798
{dara0003,asvinod,rpmahesh }@ntu.edu.sg

E. M-K. Lai

School of Engineering & Technology,
Massey University,
Wellington, New Zealand
E.Lai@massey.ac.nz

***Abstract* — In a typical multi-standard wireless communication receiver, the channelizer extracts multiple radio channels of distinct bandwidths from a digitized wideband input signal. The complexity of the digital front end of the receiver is dominated by the complexity of the channelizer which operates at the highest sampling rate in the system. Computationally efficient architecture is essential for cost-effective implementation of the channelizer. Reconfigurability is another key requirement in the channelizer to support different communication standards. In this paper, we propose a low complexity reconfigurable filter bank (FB) channelizer based on coefficient decimation, interpolation and frequency masking techniques. Design example shows that the proposed FB offers complexity reduction of 54.8% over modulated perfect reconstruction FB and 10.5% over discrete Fourier transform FB. Furthermore, the proposed FB has an added advantage of dynamic reconfigurability over these FBs.**

Keywords- Multi-standard wireless communication receivers, Channelization, Coefficient Decimation, Reconfigurability.

I. INTRODUCTION

The most computationally intensive and power consuming block in the digital front end of a multi-standard wireless communication receiver (MWCR) is the channelizer, which operates at the highest sampling rate [1]. The channelizer is employed to extract individual radio channels (frequency bands) from the wideband input signal for follow-on baseband processing [2]. In MWCRs, channelization is usually done using a digital filter bank (FB). The FB must be dynamically reconfigurable so that signal can be efficiently adapted to any frequency band. Moreover, the FB should have low complexity for efficient hardware implementation.

Discrete Fourier transform filter bank (DFTFB) is widely employed when multiple channels of the same communication standard need to be extracted. DFTFB consists of a single low pass filter followed by DFT operation [2, 3]. But DFTFBs have constraints that all the channels are of uniform bandwidth i.e. DFTFBs cannot extract channels with different bandwidths simultaneously. Therefore, distinct DFTFBs are required for each standard in MWCRs. Hence, complexity of MWCRs increases linearly with number of operating standards. A modulated FB based on a combination of polyphase FB and DFT modules has been proposed in [4]. This hybrid FB is computationally efficient when compared to conventional DFTFBs. But the FB in [4] is incapable of extracting non-uniform channels. DFTFB and its modifications are expensive when channels of multiple standards need to be extracted.

A channelizer based on modulated perfect reconstruction filter bank (MPRFB), which can extract channels of non-uniform bandwidths, is proposed in [5]. The MPRFB consists of an analysis section and a synthesis section. Bandwidths of channels extracted by synthesis section are integer multiples of bandwidth of the sub band channels extracted by analysis section which limits the flexibility of the MPRFB in a multi-standard environment. Hence, the MPRFB fails to extract channels of communication standards whose bandwidths are not related by an integer factor.

In this paper, we present a reconfigurable FB channelizer for MWCRs based on interpolation, coefficient decimation and frequency masking techniques. Reconfigurability is achieved by suitably changing decimation value, which will result in variable bandwidth channels.

The paper is organized as follows. In section II, the design of the proposed FB is explained. Section III describes the architecture of proposed FB. Section IV shows simulation results and section V presents comparison with other FBs. Section VI has our conclusions.

II. PROPOSED FILTER BANK DESIGN

In MWCRs, the FB specification varies depending on the current spectral scenario. In the conventional multi-standard FB channelizer, reconfigurability is achieved by switching among different FBs, each designed for a particular standard. But this approach leads to inefficient resource utilization and increased hardware complexity. In this paper, we present a method to realize reconfigurable FB which will allow receivers to extract multiple radio channels of different bandwidths from the received wideband signal.

The proposed FB is based on interpolation, coefficient decimation (CD) [6] and frequency masking techniques [7]. In [6], two techniques namely coefficient decimation-1 (CD-I) and coefficient decimation-II (CD-II) are proposed for the realization of reconfigurable filters. In CD-I, every D^{th}

coefficient of a finite impulse response (FIR) filter is kept unchanged and all other coefficients are replaced by zeros to get multiband response with identical passband width as that of the original filter. By changing value of D, different number of frequency response replicas located at integers multiples of $2\pi/D$ can be obtained [6]. Fig. 1(b) shows the frequency response of filter obtained using CD-I from the modal filter in fig. 1(a). In the proposed FB, the CD-I approach is used for the implementation of masking filters and is explained in details in section III. In CD-II, every D^{th} coefficients of FIR filter are grouped together discarding the in between coefficients to obtain a decimated version of original frequency response whose passband width and transition band width (*TBW*) are D times that of original filter [6]. Fig. 1(c) shows the frequency response of filter obtained using CD-II from the modal filter in fig. 1(a).The CD-II approach is used to obtain variable bandwidth frequency responses in this work and is explained later in this section. Interpolation by M consists of replacing each delay element of the FIR filter by M delay elements resulting in a filter with $(M+1)$ multiband responses having passband width and *TBW* M times smaller than the original filter [7]. The interpolation approach is used to obtain $(M+1)$-band filter and is explained later in this section.

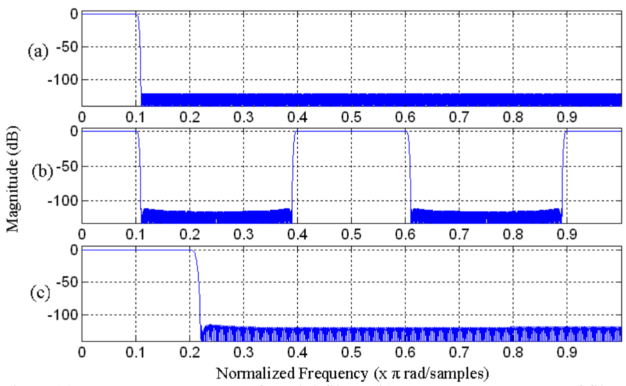

Fig. 1 (a) Frequency response of modal filter, (b) Frequency response of filter using CD-I from modal filter in (a) for $D = 2$, (c) Frequency response of filter using CD-II from modal filter in (a) for $D = 4$.

The block diagram of the proposed FB is shown in Fig. 2. It consists of two stages: 1) a low pass linear phase FIR filter called the modal filter, $H_a(z^{M/D})$, with CD-II, interpolation and complementary filter, $H_c(z^{M/D})$, to obtain multiband response and 2) bank of masking filters to extract desired channels of interest. The first stage of the FB provides distinct bandwidth channels. The number of channels depends on interpolation factor M and channel bandwidth depends on decimation factor D and interpolation factor M. The outputs of modal filter and complementary filter are fed to respective fixed masking filter banks. Each masking filter will extract the desired channel for which the masking filter is designed, by masking the frequencies of other channels. The number of masking filters depends on number of channels produced by first stage. However, number of masking filters are reduced using CD-I method thereby reducing the complexity of proposed FB. The detailed design of proposed FB is given below.

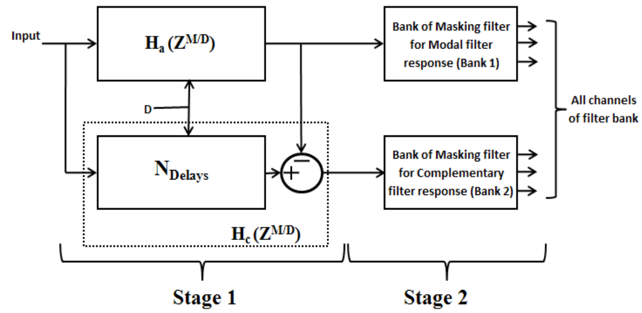

Fig. 2. Block diagram of proposed Filter Bank.

A. Design of Modal Filter

The first stage of the proposed FB architecture consists of a modal filter whose passband width can be changed using suitable decimation factor D employing CD-II. The resultant filter is interpolated by a factor of M resulting in an $(M+1)$-band filter response (i.e. $H_a(z^{M/D})$) as shown in Fig. 2) [8]. Thus the first stage provides variable bandwidth channels (sub bands), whose design steps are as follows:

1. Determine the minimum sub band bandwidth (B) of the FB taking into account of the channel bandwidths of multiple communication standards under consideration.
2. Generate an N-tap low pass filter (called modal filter) with passband and stopband edges as F_{pass} and F_{stop} respectively. All the frequency edges mentioned in this paper are frequencies normalized with respect to sampling frequency. The frequency response of the N-tap modal filter should be well within the normalized Nyquist frequency i.e. $Fstop \le 1/D$ [6]. If the required stopband attenuation (SA) of the FB is $\partial s(\mathit{filter\ bank})$, then the SA of modal filter is given as $(\partial s(\mathit{filter\ bank})/D)$ [8].
3. The value of M decides number of sub bands in FB and is kept constant for a given architecture. Depending upon M, F_{pass} and F_{stop}, D values are chosen to obtain uniform as well as non-uniform channels and meet the bandwidth, B.
4. Number of delays to obtain complementary response is given as,

$$N delays = \left\{ \left(\left\lfloor \frac{(N-1)}{D} \right\rfloor + \left(\left\lfloor \frac{(N-1)}{D} \right\rfloor \bmod 2 \right) \right) \times \frac{M}{2} \right\} \qquad (1)$$

The design process in steps (1 to 4) is shown in Fig. 3. In Fig. 3, H_a represents the modal filter response and H_c represents the complementary response. Fig. 3(a) shows the frequency response of modal filter ($H_a(z)$) and complementary filter ($H_c(z)$). In Fig. 3(b), the frequency response of decimated and interpolated modal filter response ($H_a(z^{M/D})$) and its complementary ($H_c(z^{M/D})$) when $D=D_{min}$ is shown, where D_{min} is the minimum value of D. Fig. 3(c) shows the frequency response of decimated and interpolated modal filter response ($H_a(z^{M/D})$) and its complementary ($H_c(z^{M/D})$) when $D=D_{max}$, where D_{max} is the maximum value of D.

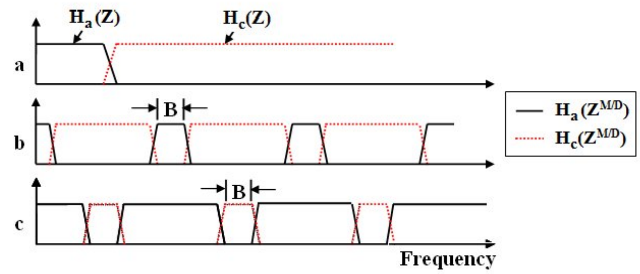

Fig. 3. Frequency response showing the design of modal filter.

B. Design of Masking Filters

The second stage of the proposed FB consists of lower order masking filters designed to extract variable bandwidth channels. Fig. 4(a) shows the variation of sub band bandwidth of modal filter ($H_a(z^{M/D})$) as D is varied. Similarly, Fig. 4(b) shows the variation of sub band bandwidth of complementary filter ($H_c(z^{M/D})$) as D is varied. As the value of D is increased from D_{min} to D_{max}, bandwidth of the sub bands in modal filter response increases and bandwidth of sub bands in complementary filter response decreases.

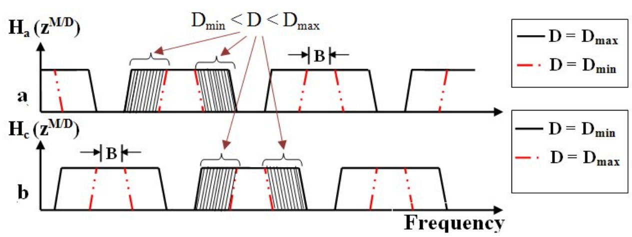

Fig. 4 Frequency response of the modal filter and complementary filter for different values of D.

The proposed FB consists of two banks of masking filters 1) for modal filter response (*Bank 1*) and 2) for complementary filter response (*Bank 2*) as shown in Fig. 2. The two masking filter banks, *Bank 1* and *Bank 2* are designed independently. The same masking filters can be used to separate the different bandwidth channels obtained using different decimation factors. Hence there is no need to reconfigure the masking filters; instead fixed coefficient masking filters can be employed. The passband and stopband frequencies of masking filters of *Bank 1* are obtained using the frequency plot of $H_a(z^{M/D})$ for $D = D_{max}$ shown in Fig. 5. Similarly, the passband and stopband frequencies of masking filters of *Bank 2* can be obtained using frequency plot of $H_c(z^{M/D})$ when $D = D_{min}$. The design equations for masking filters (as can be observed from Fig. 5) are specified below:

1. The passband frequencies of masking filter ($F_{p(mask)}$) are given as,

$$F_{p1(mask)} = F_{centre1} - TBW_{filterbank(\max)} + B/2 \qquad (2)$$
$$F_{p2(mask)} = F_{centre2} + TBW_{filterbank(\max)} - B/2$$

2. Similarly, stopband frequencies of masking filter ($F_{s(mask)}$) are given as,

$$F_{s1(mask)} = F_{centre1} + TBW_{filterbank(\max)} - B/2 \qquad (3)$$
$$F_{s2(mask)} = F_{centre2} - TBW_{filterbank(\max)} + B/2$$

where B is the minimum channel bandwidth, ($F_{centre1}$,$F_{centre2}$) are the centre frequencies of adjacent bands in the complementary response as shown in Fig. 5 and $TBW_{filter\ bank\ (max)}$ is the maximum transition bandwidth.

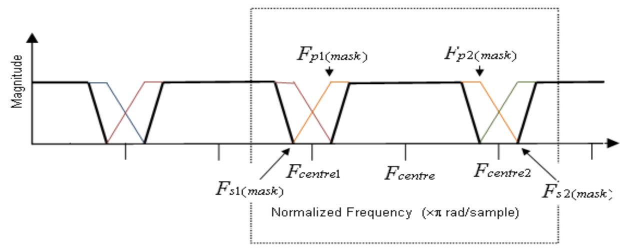

Fig. 5. Frequency plot indicating the passband and stopband frequencies of masking filter when $D = D_{max}$.

For *(M+1)*-channel FB, conventional approach is to use one masking filter with passband and stopband frequencies given by equation (2) and (3) for each channel. Though this approach reduces design effort significantly, it leads to increase in hardware complexity and power requirement. It is not necessary to design separate masking filter for each channel. The number of masking filters can be reduced significantly by employing the CD-I approach, which is explained in more details in Section III.

III. FILTER BANK ARCHITECTURE

In this section, we present the reconfigurable architecture of the proposed FB. For illustrative purpose, we have chosen $B = 0.06$ and $M = 8$ so that a 9-channel filter bank is obtained. The F_{pass} and F_{stop} of modal filter are selected as 0.1 and 0.115 respectively. The decimation factor D is varied from 3 to 7. For $D = 5$, all the 9 channels are of uniform bandwidth (identical to that of the DFTFB). The length of the modal filter obtained using Bellanger's formula [9] is 421.

The two stages of the proposed FB are shown in Fig. 6 and Fig. 7. The first stage consists of modal filter with CD-II, interpolation and complementary delays. Modal filter ($Ha(z^{M/D})$) provides two outputs A and B depending upon the value of D. The modal filter output A is given directly to the second stage. Fig. 8 and 9 show the frequency response of the modal filter obtained by varying D from 3 to 7 for $F_{pass} = 0.1$, $F_{stop} = 0.115$ and $F_{pass} = 0.067$, $F_{stop} = 0.082$ respectively. The complementary response C is obtained by subtracting B from an appropriate delayed version of input signal. The delay values are calculated using (2). The control signal *Sel* (2:0) is used to select appropriate delayed version of input depending on the value of D. When *MSB* of *Sel* signal i.e. *Sel* (2) is 1, delayed input corresponding to $D = 5$ is selected. Similarly, for $D = 3$, *Sel* is 000 and so on.

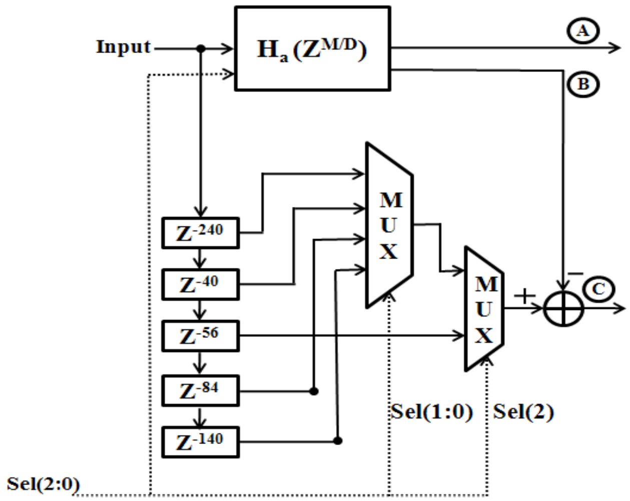

Fig. 6.Architecture of first stage of proposed FB.

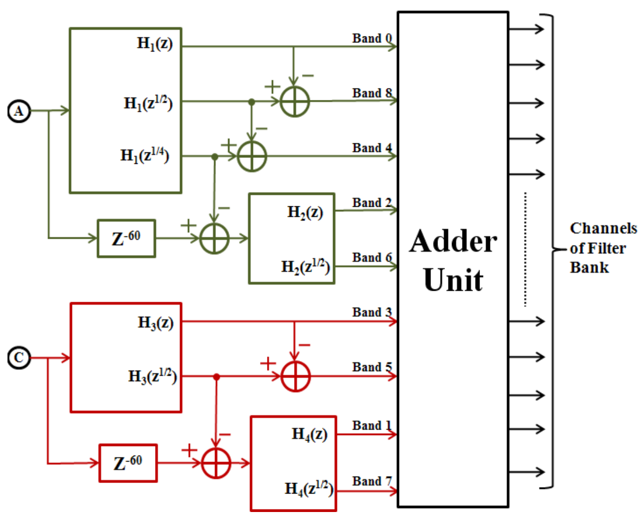

Fig. 7. Architecture of second stage of proposed FB.

Both outputs *A* and *C* are passed to the second stage shown in Fig. 7. The second stage consists of masking filters and adder unit (AU). The masking filters are used to extract all channels obtained from stage-1 and are designed using equations (2) and (3). The AU combines adjacent bands to extract channels of varying bandwidths in order to obtain channels of wider bandwidths. Using conventional masking techniques, 9 masking filters are required to separate 9 bands (*band-0* to *band-8*) shown in Fig. 8 and 9. However, advantages of CD-I can be used to reduce the number of masking filters from 9 to 4. First masking filter $H_1(z)$ is designed to extract *band-0*. Then using CD-I with values of D as 2 and 4 on first masking filter, *band-8* and *band-4* can be extracted respectively. Thus, using a single masking filter and CD-I, three bands can be extracted. Finally, *band-2* and *band-6* can be extracted by using single lower order low pass masking filter $H_2(z)$ and its CD-I with $D = 2$.

The band pass masking filter $H_3(z)$ is used to extract *band-3* in complementary response and its CD-I with $D = 2$ is used to get *band-5*. Finally, *band-1* and *band-7* can be extracted by using lower order masking filter $H_4(z)$ and its CD-I with $D = 2$. Thus, the CD technique allows us to reduce number of masking filter providing computationally efficient architecture. The proposed architecture offers reconfigurability at two levels, filter level and architectural level.

A. Filter level reconfigurability

In MWCRs, reconfigurability must be accomplished by reconfiguring the same FB for a new communication standard with minimal reconfiguration overhead, instead of employing separate FB for each standard. In the proposed FB, reconfigurability is achieved by suitably changing the decimation values for a fixed interpolation value to extract channels of different bandwidth. Theoretically, we can achieve $(M+1)\mathrm{x}(D_{max}–D_{min}+1)$ number of channels of different bandwidths. In the above design example, the decimation factor is varied from 3 to 7 and a fixed value of M (=8) is used. Thus, 9x(7-3+1) = 45 channels of different bandwidths can be extracted using only 4 masking filters as shown in Fig. 7. The specifications of all the channels corresponding to $D = 3$ to 7 for modal filter with $F_{pass} = 0.1$, $F_{stop} = 0.115$ and $F_{pass} = 0.067$, $F_{stop} = 0.082$ are listed in Table I.

Another level of reconfigurability can be exploited by reconfiguring the coefficients of modal filter. However, there is limitation on minimum and maximum values of F_{pass} and F_{stop} of modal filter such that BW of channels is not less than B. From Fig. 3, it is clear that we get channels of bandwidth B when D is D_{min} or D_{max}. Hence, the maximum passband frequency of modal filter ($F_{pass(max)}$) for $(M+1)$–channel filter bank is given by,

$$Fpass(\max) = \left\{\left(\frac{1}{M}-\frac{B}{2}\right)\times\frac{M}{D\max}\right\}. \qquad (4)$$

Minimum passband frequency of modal filter ($F_{pass(min)}$) for $(M+1)$–channel filter bank is given by,

$$Fpass(\min) = \left\{\frac{M\times B}{D\min\times 2}\right\}. \qquad (5)$$

The maximum and minimum stop band frequencies ($F_{stop(min)}$, $F_{stop(max)}$) of modal filter are obtained by adding *TBW* of modal filter to corresponding passband frequencies such that $\{F_{stop(max)} \mathrm{x} D_{max} < 1\}$ to avoid aliasing. The advantage of the proposed filter bank is that only 4 masking filters are needed to extract all $K(M+1)(D_{max} – D_{min} +1)$ channels corresponding to K modal filters with $F_{stop(min)} \leq F_{stop} \leq F_{stop(max)}$, $F_{pass(min)} \leq F_{pass} \leq F_{pass(max)}$. For $K = 2$, we can extract 90 channels of distinct bandwidths.

B. Architecture level reconfigurability

The proposed architecture can extract channels corresponding to the different values of D simultaneously. For example, we can have $D = 3$ for $H_a(z^{M/D})$ and $D = 7$ for $H_c(z^{M/D})$. Also, when factor D for $H_a(z^{M/D})$ and $H_c(z^{M/D})$ is same, then adjacent channels of filter bank can be combined.

Simulation results presented in section IV shows the significance of architectural reconfigurability in channelization task.

IV. Simulation Results

In this section, the simulation results of the proposed FB are presented. Fig. 10 and 11 show the spectra of the input signal and that of the output signal extracted using proposed FB architecture. A wideband input signal as shown in Fig. 10(a) and 11(a) are given to the proposed FB. The individual extracted channels are shown in Fig. 10 (b)-(e) and 11(b)-(e) respectively. The mean square error (MSE) between the samples of extracted channels and respective samples of input signal for the results shown in Figures 10 and 11 is given in Table II. Note that the errors are low.

TABLE II. MSE FOR DIFFERENT CHANNELS

Channels \ MSE	MSE for Fig. 10.	MSE for Fig. 11.
Channel 1	0.1004	0.1054
Channel 2	0.0366	0.0494
Channel 3	0.0197	0.0278
Channel 4	0.0992	0.0614

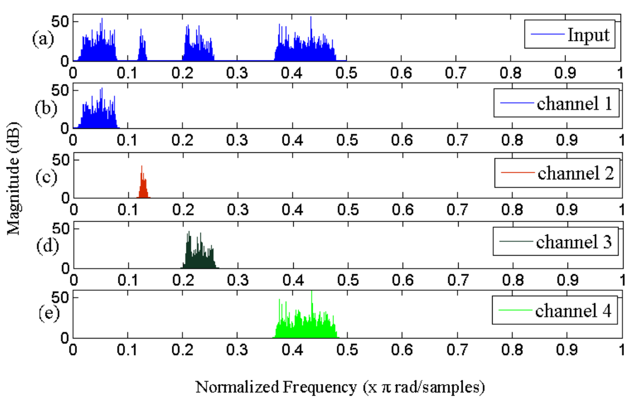

Fig. 10 (a) Input signal consisting of 4 channels, (b) – (e) Extracted channels 1 to 4 using proposed filter bank.

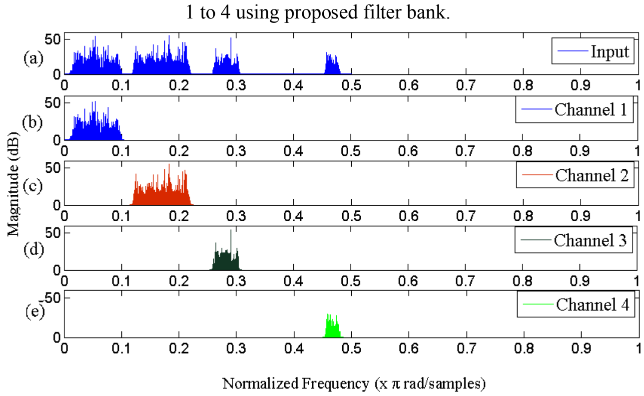

Fig. 11 (a) Input signal consisting of 4 channels, (b) – (e) Extracted channels 1 to 4 using proposed filter bank.

V. Complexity Comparison

Since multiplication is the most complex and power consuming operation in a digital filter bank, we consider number of real-valued multiplication for comparing the complexity of FBs. As the proposed FB can produce uniform as well as non-uniform FB response, it is fair to compare the proposed FB with uniform bandwidth DFTFB and non-uniform bandwidth MPRFB. In the proposed FB, filter length of modal filter is 421. Similarly, length of masking filters $H_1(z)$, $H_3(z)$ is 121 and that of $H_2(z)$, $H_4(z)$ is 41 using Bellanger's formula [9]. As modal filter and all masking filters have symmetrical coefficients, number of multiplications is $\lceil N/2 \rceil$, where N is the filter length. Thus the number of multiplications in our design example is 211 for modal filter, 61 each for $H_1(z)$, $H_3(z)$ and 21 each for $H_2(z)$,$H_4(z)$. Also, as CD-II is employed, 72 out of 211 modal filter coefficients are discarded. Thus total number of real multiplications is 139 + 61 + 61 + 21 + 21 = 303.

The proposed FB divides spectrum from 0 to $F_s/2$ (where F_s is sampling frequency) into 9 channels. As mentioned in Section IV, the proposed FB produces output similar to 16-channel DFTFB and 16-channel MPRFB when D = 5 with F_{pass}=0.1 and F_{stop} = 0.115. For 16-channel DFTFB with -30dB stopband attenuation, total number of real multiplications is 335 (271 for prototype filter + 64 for DFT calculation). As complexity of MPRFB is double than that of DFTFB, total number of real multiplications is 650. Thus the proposed FB offers complexity reduction of 54% over MPRFB, 8% over DFTFB for D = 5 case.

VI. Conclusion

We have presented a new reconfigurable uniform and non-uniform FB architecture based on interpolation, coefficient decimation and frequency masking techniques for MWCRs. The proposed FB is capable of extracting channels of different bandwidths corresponding to multiple wireless communication standards from the digitized wideband input signal. Design example shows that the proposed FB offers complexity reduction of 54.8% over MPRFB, 10.5% over DFTFB. Also, proposed FB has an added advantage of dynamic reconfigurability over these FBs.

References

[1] J. Mitola, Software Radio Architecture. New York: Wiley, 2000.

[2] Lee Pucker, *Channelization Techniques for software defined radio,* Proceedings of SDR Forum Technical Conference,Orlando,2003,http://www.spectrumsignal.com/channel_techniques/channelization_paper_sdr_forum.pdf.

[3] T. Hentschel, "Channelization for software defined base-stations," Annales des Telecommunications, ISSN 0003-4347, vol. 57, pp. 386-420, no. 5-6, May-June 2002.

[4] K. Chonghoon, S. Yoan, I. Sungbin, and L. Woncheol, "SDR-based digital channelizer/de-channelizer for multiple CDMA signals," in Proc. of the *Vehicular Technology Conferen 52nd*, 2000, pp. 2862-2869 vol.6.

[5] W. A. Abu-Al-Saud and G. L. Stuber, "Efficient wideband channelizer for software radio systems using modulated PR filterbanks," *IEEE Transactions on Signal Processing*, vol. 52, pp. 2807-2820, 2004.

[6] R. Mahesh and A. P. Vinod, "Coefficient decimation approach for realizing reconfigurable finite impulse response filters," *Proceedings of IEEE international symposium on circuits and syatems*, seattle USA, May 2008.

[7] Y. C. Lim, "Frequency-response Masking Approach for the Synthesis of Sharp Linear Phase Digital Filters", IEEE Trans. Circuits. Syst., vol. 33, pp. 357-364, Apr. 1986.

[8] K. G. Smitha and A. P. Vinod, "A new low power reconfigurable decimation-interpolation and masking based filter architecture for channel adaptation in cognitive radio handsets," *Physical Communication,* vol. 2, pp. 47-57, 2009/6//.

[9] M. Bellanger, "On computational complexity in digital filters," in *Proc. of the European Conference on Circuit Theory and Design*, Haugue, Netherlands, pp. 58-63, August 1981.

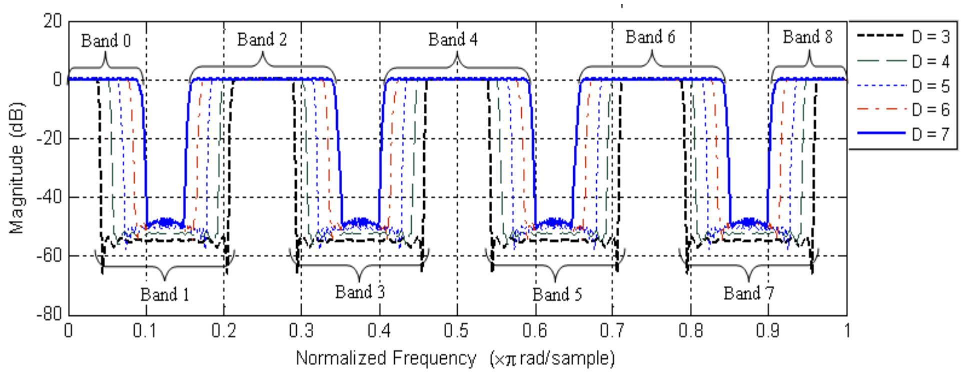

Fig. 8. Channel bandwidth variation for modal filter with F_{pass} =0.1 and F_{stop} = 0.115, for different decimation (*D*) factors.

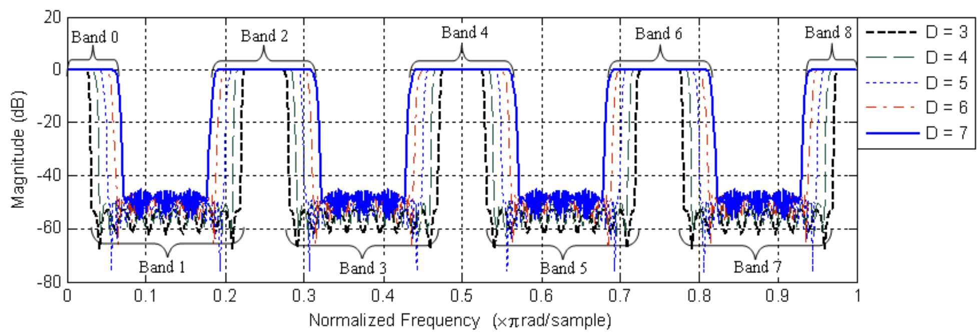

Fig. 9. Channel bandwidth variation for modal filter with F_{pass} =0.06 and F_{stop} = 0.075, for different decimation (*D*) factors.

TABLE I. SPECIFICATION OF PASSBAND AND STOPBAND FREQUENCIES OF CHANNELS FOR DIFFERENT MODAL FILTERS

Band No.	*D*	Modal filter specifications							
		F_{pass} = 0.1 and F_{stop} = 0.115				F_{pass} = 0.06 and F_{stop} = 0.075			
		F_{stop1}	F_{pass1}	F_{pass1}	F_{stop2}	F_{stop1}	F_{pass1}	F_{pass1}	F_{stop2}
1	3			0.0375	0.049			0.0225	0.0281
	7			0.0875	0.1			0.0525	0.0656
2	3	0.0375	0.049	0.201	0.2125	0.0225	0.0281	0.2219	0.2275
	7	0.0875	0.1	0.15	0.1625	0.0525	0.0656	0.1844	0.1975
3	3	0.201	0.2125	0.2875	0.299	0.2219	0.2275	0.2725	0.2781
	7	0.15	0.1625	0.3375	0.35	0.1844	0.1975	0.3025	0.3156
4	3	0.2875	0.299	0.451	0.4625	0.2725	0.2781	0.4719	0.4745
	7	0.3375	0.35	0.4	0.4125	0.3025	0.3156	0.4244	0.4475
5	3	0.451	0.4625	0.5375	0.549	0.4719	0.4745	0.5225	0.5281
	7	0.4	0.4125	0.5875	0.6	0.4244	0.4475	0.5525	0.5656
6	3	0.5375	0.549	0.701	0.7125	0.5225	0.5281	0.7219	0.7275
	7	0.5875	0.6	0.65	0.6625	0.7219	0.7275	0.6844	0.6975
7	3	0.701	0.7125	0.7875	0.799	0.7219	0.7275	0.7725	0.7781
	7	0.65	0.6625	0.8375	0.85	0.6844	0.6975	0.8025	0.8156
8	3	0.7875	0.799	0.951	0.9625	0.7725	0.7781	0.9719	0.9775
	7	0.8375	0.85	0.9	0.9125	0.8025	0.8156	0.9344	0.9475
9	3	0.951	0.9625			0.9719	0.9775		
	7	0.9	0.9125			0.9344	0.9475		