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Optimal Resource Allocation in Terahertz Band Using Modified Waterfilling Algorithm

Arshdeep and Khushal Thakur
Department of Electronics and Communication Engineering,
Chandigarh University, Gharuan, 140413 Mohali, Punjab, India

Abstract: With wireless communication increasingly becoming popular and convergent, service providers have to continuously upgrade their networks in order to support increasing demand for bandwidth. In this regard communication in terahertz band is considered as an indispensable technology which assures data rate needs of upcoming wireless networks. In this study, a modified waterfilling algorithm is proposed for multi-user system with an objective to perform optimal resource allocation. This improved model enhances system performance in contrast to conventional scheme and attains largest possible capacity. Compared to conventional scheme, altered waterfilling model is deployed in multi-user system to evaluate data rate with distance consideration. We obtain power allocated and data rate using the algorithm and based on simulation results we indicate that proposed researcher outperforms existing technique.

Key words: Channel capacity, resource allocation, terahertz band, waterfilling algorithm, service, system

INTRODUCTION

With the expeditious proliferation of wireless networks and smart phones, data traffic is increasing swiftly. The global mobile data traffic amounted to 7 EB (Exabyte) per month in year 2016 is expected to reach 49 EB per month in 2021 at a compound annual rate of 47%. Therefore, the exigency for higher throughput in mobile networks has acutely multiplied, leading to opportunistic utilization of white spaces mainly in the Terahertz (Thz) band. The Thz band is the spectral band that ranges the frequencies between 0.1-10 THz. This band is utilized to consider capacity diminution and insufficiency of spectrum in prevailing wireless set-ups and fosters surfeit of applications including a secure and reliable wireless communication, data passing among contiguous devices at rapid pace and ultra high speed backhauls to nano and microcell networks.

This Extremely High Frequency (EHF) spectrum also termed as terahertz gap can be employed by Cognitive Radio (CR) technology (Akyildiz *et al*., 2006) where the radio terminals in a CR network sense the spectrum to detect white spaces for establishing communication in a vacant channel without interference to the primary user. MIMO-OFDM is another key innovation in high information rate frameworks as 4G, IEEE 802.16, Digital Audio Droadcasting (DAB), Digital Video Broadcasting (DVB-T) and ATSO. Multiple-Input Multiple-Output Orthogonal Frequency Division Multiplexing (MIMO-OFDM) (Rostami *et al*., 2015; Forooshani and Michelson, 2015) is prepollent air interface for 4G and 5G radio broadcasting in which the MIMO technology proliferates capacity by passing diverse signals over numerous antennas and OFDM apportions the wireless channel multiple abreast sub-channels to render reliable transmission at rapid pace. In light of the fact that OFDM utilizes large number of narrowly spaced sub-channels an ideal water filling capacity can be attained using adaptive techniques where different sized signal constellations are transmitted on the sub-carriers. Water filling algorithm practices equalization strategies on communication channels in communication networks to compensate for the channel impairments and to obtain power levels with high efficiency and low computational complexity.

Thus, in WF method power is assigned based on channel gain of subcarrier. The improved model includes wide range of computational algorithms to solve deterministic problems having probabilistic interpretations. Based on limitations of capacity and total power of each subcarrier, a modified waterfilling scheme is employed which has great merit in complexity of operations against the conventional technique in same condition. Therefore, a modified waterfilling allocation algorithm is proposed to enhance the system performance, computational efficiency and achieve optimal sum capacity. So, our proposal of improved

Corresponding Author: Arshdeep and Khushal Thakur, Department of Electronics and Communication Engineering, Chandigarh University, Gharuan, 140413 Mohali, Punjab, India

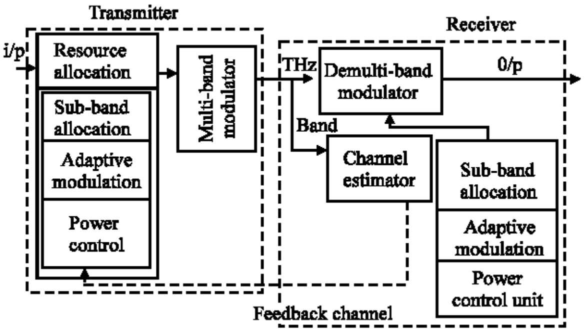

Fig. 1: THz band channel system model (Han and Akyildiz, 2016)

version of the aforementioned scheme encompasses small count of active users supported by multi-user diversity so as to compute channel capacity. Thus, the intuitive strategy intents to diminish number of transmit spatial dimensions for best effort data.

In this study, we develop a scheme for optimal assignment of resources in THz band network using an improved waterfilling algorithm with the purpose to enhance capacity over distance. The formulated scheme considers channel specifications including distance-bandwidth relation and strategically uses spectrum to increase data rates. The inter-related resource allotment operations are perceived in control unit of the system model shown in Fig. 1. Therefore, the predominant aspects instantiated in study are precised as: developing an optimal joint sub-carrier and power allocation scheme in THz band communication network with an aim to improve distance and concurrently assist multiple ultra high speed links. The proposed allocation scheme is furnished using waterfilling algorithm to enhance capacity and also applying modified version of model, i.e., waterfilling to evaluate deterministic problems related to users. The optimization framework for users in communication networks is formulated with objective to increase capacity in THz range.

Erahertz band delineation: This segment presents a general review of the THz band channel, the transmission windows and its analogous aspects.

Terahertz band overview: Terahertz band is incorporeal band that spans frequencies between 0.1-10 THz (Han, 2016). Therefore, for accomplishment of optimal wireless set-ups in this band it is crucial to formulate a unified channel model.

Channel modelling: A coalesced multi-ray model for complete terahertz ambit is undertaken for assimilating explicit characterization of Line-of-Sight (LoS), diffracted, scattered and reflected paths and is developed using ray-tracing scheme (Han *et al*., 2015). Considering time, t during impulse response and τ as propagation delay, the multi-ray model has channel response as:

$$h_k(\tau, t) = \sum_{m=1}^{N_k(t)} \alpha_{k,m}(t)\delta(\tau-\tau_m) \tag{1}$$

Where:
$\tau_m = \tau_m/c$ = Delay of mth path
r_m = Travelling distance
c = The speed of light

If there are $N(k)_{ref}$ reflected rays $N_{sca}^{(k)}$ as scattered rays, $N_{Dif}^{(k)}$ diffracted rays in kth frequency span, the representation can be recounted as:

$$\begin{aligned} h_k(\tau) = {} & \alpha_{Los}^{K}\delta(\tau-\tau_{LOS})1_{Los} + \sum_{l=1} N_{Ref}^{k}\alpha_{Ref}^{(k,l)}\delta\left(\tau-\tau^{l}_{Ref}\right) + \\ & \sum_{p=1}^{N_{Sca}^{k}} \alpha_{sca}^{(k,p)}\delta\left(\tau-\tau_{sca}^{(p)}\right) + \sum_{q=1}^{N_{Dif}^{k}} \alpha_{Dif}^{(k,q)}\delta\left(\tau-\tau^{q}_{Dif}\right) \end{aligned} \tag{2}$$

Where:
1_{Los} = Idicator function
α = Atenuation
τ = Delay

By invoking Weiner-Khinchin theorem, delays and attenuations in kth frequency sub-band can be given as:

$$\begin{pmatrix} \alpha_{Los}^{(k)} \\ \alpha_{Ref}^{(k,l)} \\ \alpha_{sca}^{(k,p)} \\ \alpha_{Dif}^{(k,q)} \end{pmatrix} = \begin{vmatrix} H_{Los}(f_k) \\ H_{Ref}^{l}(f_k) \\ H_{sca}^{p}(f_k) \\ H_{dif}^{q}(f_k) \end{vmatrix} \tag{3}$$

Where:
H = Transfer function
f_k = Centre frequency in kth sub-band

Transmission windows: To logically indicate the spectral windows assorted on distance, the path loss threshold (Pl_{tk}) is explicated. A methodical result to Pl_{tk} in db is procured using link budget in Eq. 5:

$$PL_{th} = P_T + G_T + G_R - \gamma_{th} - P_n \tag{4}$$

Where:
P_T and P_n = Transmit power and total noise power at receiver
G_T and G_R = Transmitter and Receiver Gain
γ_{th} = Threshold SINR (Han *et al*., 2016)

The spectral windows formed as a result of path loss peaks created from absorption losses varies with

Table 1: Iznitial transmission windows for THz communication (Han and Akyildiz, 2014)

r = 1 m (THz)	r = 0.1 m (THz)	r = 10 m (THz)
0.10-1.659	0.100-4.511	0.100-0.552
1.674-1.713	4.514-6.074	0.562-0.748
1.712-2.162	6.079-6.829	0.756-0.984
2.167-2.194	6.832-7.612	0.991-1.086
2.198-2.219	7.616-9.082	1.120-1.147

distance and few peaks occur at 0.56, 0.75 and 0.98 THz. In specific when r = 0.1 m the first transmission window is 4.41 THz wide which shrinks to 1.559 and 0.452 THz at r = 1 and 10 m, respectively. In contrast for r = 10 m there are non-consecutive 98 windows with bandwidth dwindling to 5.90 THz (Han and Akyildiz, 2016) (Table 1).

Channel capacity: The channel capacity in THz band is evaluated by fractionation of the signal received as aggregate of sub-bands. By altering entire transmit power from 0-10 dBm (Jornet and Akyildiz, 2011) capacity of channel can be assessed for various transmission distances, propagation and power allocation strategies. Using waterfilling power allocation scheme, multipath capacity enhances with transmit power upto 75 GB whereas mean capacity decreases by 89%.

Design specifications: There is efficacious link between distance, spectral windows and usable BW which actuates adopting of adaptive and optimal resource allocation schemes for transmission in communication networks. For instance, in MP propagation with r = 5 m, the spectrum above 0.1 THz can't be used due to large path loss (Han, 2016). Though OFDM is recommended for 60 GHz system to improve efficiency of channel (Daniels and Heath, 2007) BW in sub-millimetre range is adequate.

Resource allocation using modified waterfilling model in multi-user: In this study, we formulate a system model based on optimal and adaptive resource allocation scheme so, as to increase capacity for user communication over a specified communication range. By escalating data rate, dividing spectrum into multiple sub-channels and allocating each subcarrier to a user this can be achieved. Subcarrier allocation is predominant facet in OFDM system that is carried out analyzing sub-channel quality. Initially sub-channel is allocated to SU so as to achieve maximum transmission rate and leftover sub-channels to CR. A waterfilling approach is used to allocate power based on channel gain of subcarrier. Rather than applying Interference Power Constraint (IPC) to secure PU's the proposed power allocation scheme procured under Rate Loss Constraint (RLC) is desirable for acquiring substantial rate gains (Safia and Rajitha, 2013).

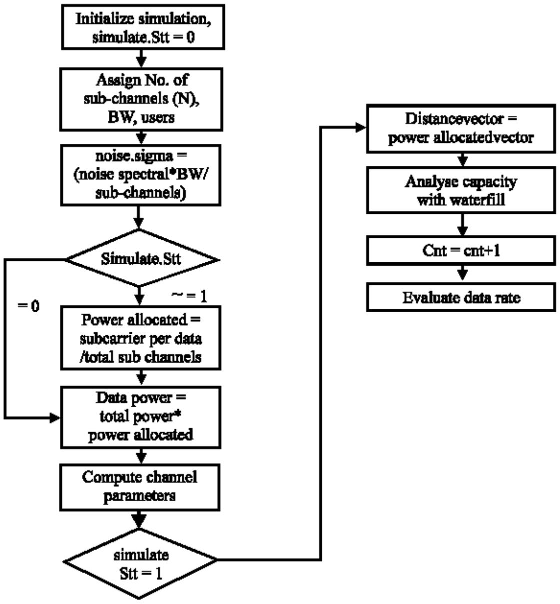

Fig. 2: Flowchart for multi-user resource allocation using modified waterfill mode

The Waterfilling Algorithm (WFA) is put into operation as a distributed power control algorithm for MIMO Gaussian interference channels for multi-user spectrum optimization problem. In WFA each user insistently upgrades its own transmit power while escalating its utility function by considering interference occurring from other users as noise. This follows simple visual interpretation of pouring water into a vessel with its surface expounded by inverse channel gain (Forooshani and Michelson, 2015) if its value is small more power is assigned in equivalent subcarrier and when inverse channel gain increases power is remarkably reduced. We can increment or decrement power levels using waterfill process as it's analogous to barometric pressure model. The barometric pressure on specific water levels is greater than on common water level. Due to this difference water doesn't flow from one sub-channel to another even levels of sub-channels are uneven. But uneven water levels can still acquire maximum capacity. The waterfilling approach is as follows (Fig. 2):

- Initialize number of sub-channels, N
- Attain SNR value for subcarriers, powerASNR
- Sort channel gain in order, CHA
- Set water level and obtain function value
- Obtain transmission power (which is assorted among various channels)
- Compute channel capacity

The modified waterfilling model: In MIMO-OFDM systems, waterfilling process fulfills the convergent condition by persistently closing to optimum value. Therefore, targeting to solve problem a modified waterfilling algorithm is proposed based on capacity and total power restrictions. It dynamically assigns power and subcarriers to users distinctively, grouping number of subcarriers into chunk resource to accomplish complexity reduction of resource allocation in OFDM system (Fig. 2). Consequently we consider relation between capacity and user traffic for each subcarrier which demonstrates performance of modified algorithm is better when subcarriers is more and users demand high QoS keeping BER fixed. Some effective users have greater channel gain can be chosen to compute capacity, so, larger the capacity more is transmission ability of channel. For optimising capacity and improving data rates, modified waterfill algorithm is proposed in which SNR related to sub-channels is evaluated such that power of respective sub-channels is assigned. The parameter concerned with SNR in sub-channels can be given mathematically as:

$$H = \left(\mathrm{ChA}\right)^2 / \left(\mathrm{B*No/N}\right) \quad (5)$$

Where:

ChA = Channel gain
B = Bandwidth
No = Noise spectral value
N = No. of sub-channels

The power allocated is expressed as:

$$\mathrm{PowerAllo} = \left(\mathrm{Plot+sum}\left(\mathrm{I/H}\right)/\mathrm{NA}\text{-}\left(\mathrm{I/H}\right)\right)$$

Where:

P_{tot} = Total power
NA = Length of sub-channels

RESULTS AND DISCUSSION

The plots of Fig. 3, depicts comparison amongst the resource allocation performed in THz band using modified waterfill model and conventional waterfill model. Above plot of data rate versus distance and respective co-ordinate values depicted in Table 2 indicate maximization of data rate with distance based on improved

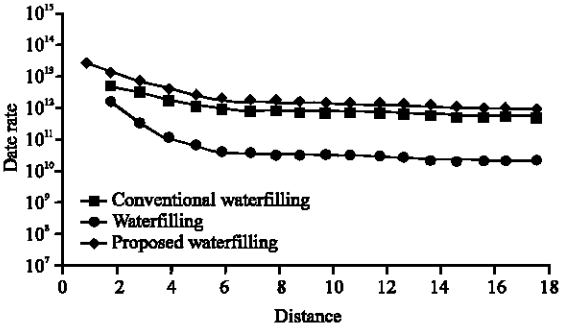

Fig. 3: Data rate in multi-user THz band communication

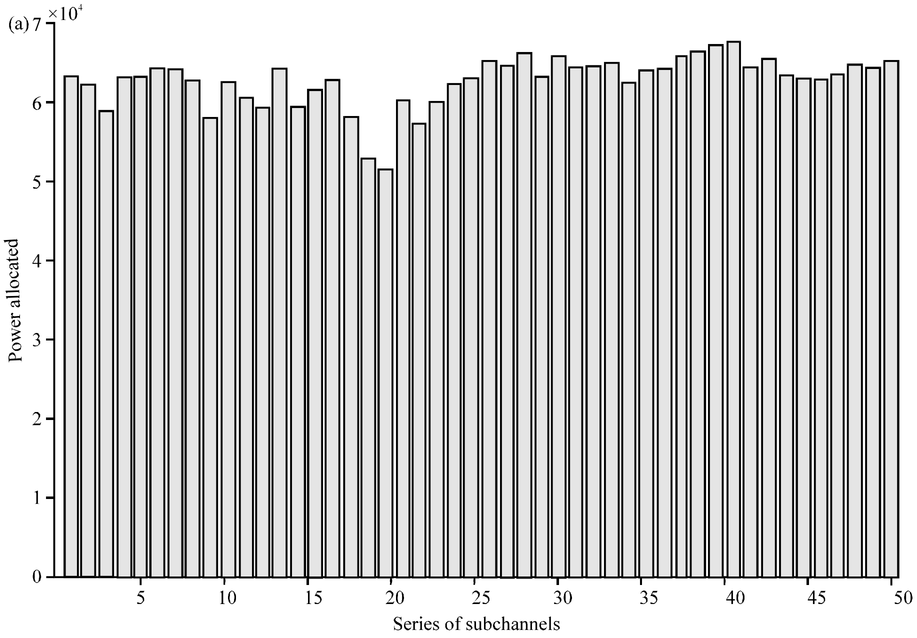

Fig. 4: Continue

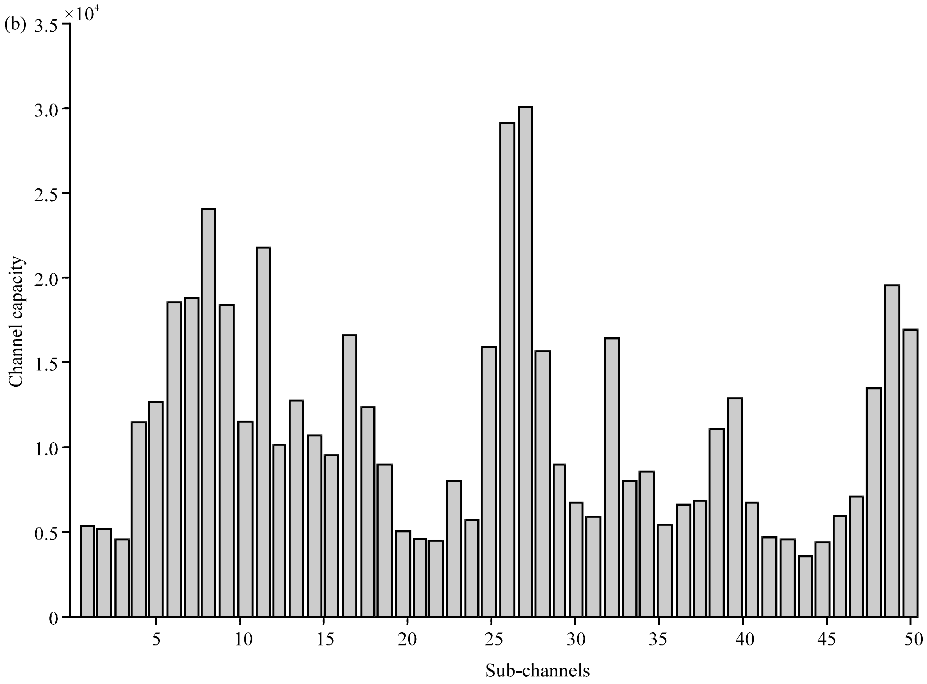

Fig. 4: a) Power allocated to series of data subcarriers and b) Capacity versus series of sub-channels

Table 2: Coordinate values depicting data rate against distance using waterfilling algorithm

Existing waterfilling algorithm (co-ordinates)		Modified waterfilling algorithm(co-ordinates)	
X	Y	X	Y
1	Non	1	2.66e+13
2	1.48e+12	2	1.31e+13
3	3.65e+11	3	7.31e+12
4	1.52e+11	4	4.18e+12
5	8.91e+10	5	2.71e+12
6	5.29e+10	6	1.99e+12

waterfill algorithm in multi-user system so as to provide optimal resource allocation. Figure 4a is illustrative of the power allocated to data subcarriers.

It reveals that system bandwidth is split into series of sub-channels and optimal power allocation is performed based on proposed waterfilling concept. From Fig. 4b, it can be demonstrated that capacity of full channel state information for given pilot power is evaluated as 2.6919, whereas power allocation capacity is 2.1481. Also, the maximum iterative capacity for pilot power is 2.1495. Therefore, it can be stated that a system with full CSI achieves maximum capacity using our proposed waterfilling scheme.

CONCLUSION

Terahertz band 0.1-10 THz communication is visualized to fulfil need of ultra wideband communication and employment of this spectral band ideates overcoming of system incapacity and spectrum limitations. In this study, we have formulated the optimal resource allocation technique in THz band using modified waterfilling model. Based upon this we have computationally and analytically evaluated data rate taking into consideration number of subcarriers, bandwidth and average Signal-to-Noise Ratio (SNR). The improved waterfill is compared to conventional algorithm in order to draw out the variation in performance and eventually attain maximum throughput which encompasses increase in overall system capacity.

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