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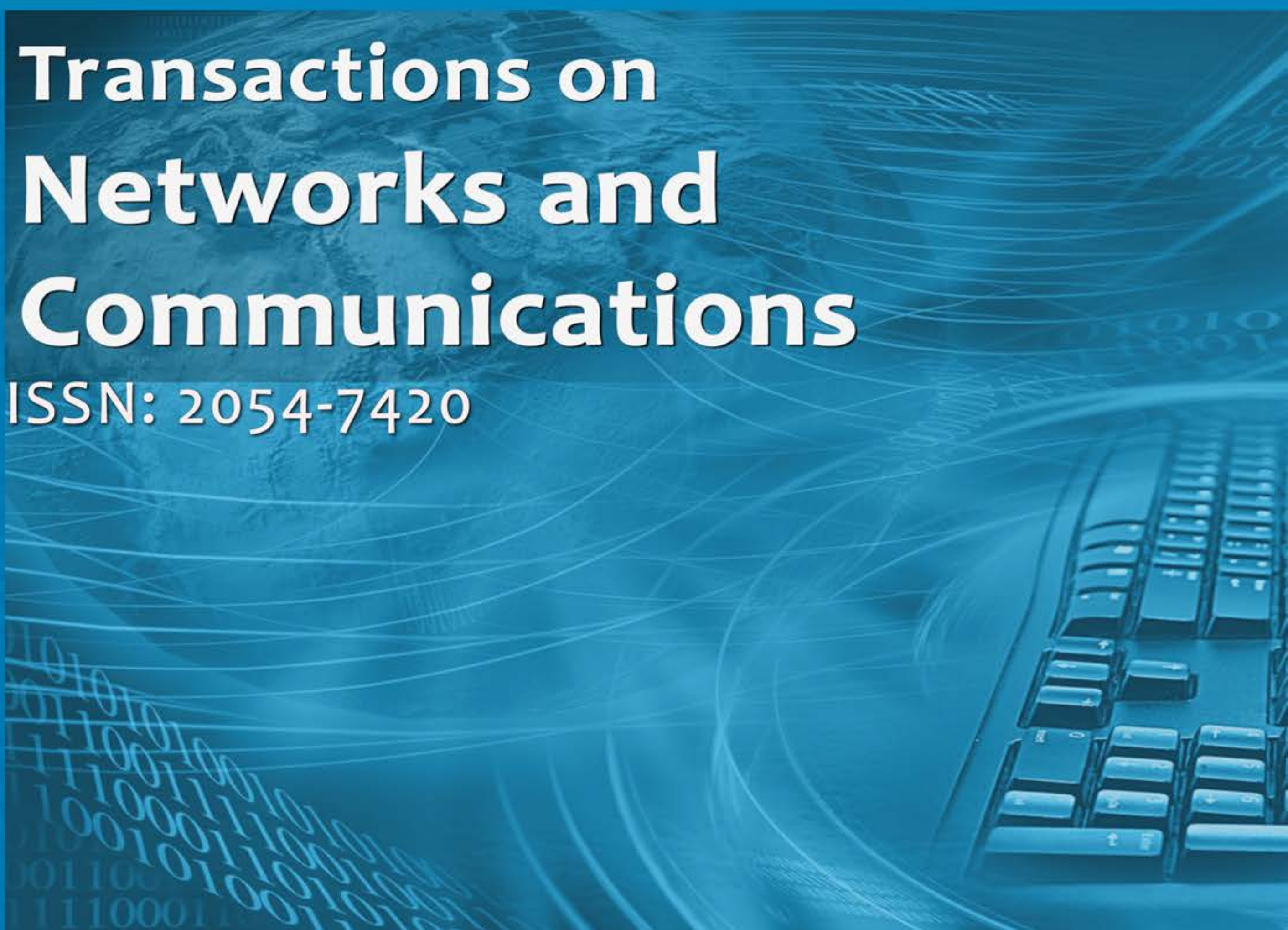

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# Traffic Management in 5G Mobile Networks: Selfish Users and Fair Network

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**ABSTRACT**

With increasing in heterogeneity of the mobile and wireless networks, including the use of licensed and unlicensed spectrum, and diversity in types of User Equipment (UEs), managing how traffic flows through network while maintaining high level of users' quality of experience is crucial. In this paper, we present a novel traffic management mechanism that maintains the users' quality of experience as well as guaranteeing fairness among users. This traffic management has two separate elements, one that is located at the UE and one that is located at the cloud-based network controller. While each UE maximizes their utility function, which is modelled based on the QoS parameters, selfishly, at the network side, the attempt is to maximize fairness among all users' flows.

**Keywords:** 5G mobile; QoS; Fairness; traffic management; LTE; WiFi; SDN; central controller.

## 1 Introduction

The next generation of mobile networks, a.k.a. 5G, will be deployed with dense small cells of different technologies including LTE femtocells and picocells, WiFi access points, and novel radios, such as millimeter wave. Faced with an ever larger portfolio of applications to serve and with a corresponding number of requirements to satisfy, it is commonly recognized that 5G need to consider various requirements of different application domains and industry sectors.

To address the above, there has been number of initiatives for the design of new mobile network architecture. One of the avenues for the 5G architecture design is the fully decoupled architecture. Decoupling of uplink and downlink has been well studied over the past few years [1] and its pros and cons are discussed in the community. Decoupling of the control and data plane is another well-investigated topic that is mostly studied within the context of Software-defined Networking (SDN) [2], [3]. Virtualisation and cloudification of the mobile networking functionalities is another element of 5G network that is enabled in such a decoupled architecture [4].

On the other hand and with the ever increasing data traffic in mobile networks, traffic management and maintaining Quality of Service (QoS) is more than ever challenging. According to Cisco Visual Networking Index, global mobile data traffic reached the 2.5 exabytes per month at the end of 2014, and this figure will surpass 24.3 exabytes by 2019 [5]. Hence, more efficient traffic managements are needed that can deal with the backhaul congestion, and guarantee the QoS for users. In the SDN-based 5G network, it

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has been shown that centralized traffic management mechanism can provide guaranteed QoS and more efficient traffic management [6].

To this end, we discussed a device-controlled mechanism in our previous work [7], where all decisions are made at the User Equipment (UE). Such device-controlled decision making mainly focuses on the users' QoS requirements and is a fully "selfish" decision. We designed the algorithm for selecting radio access at the UE with a reinforcement learning process that takes Received Signal Strength (RSS) and battery status of the UE into consideration. Here, we extend our previously designed device-controlled traffic management to address the issue of fairness, i.e. while users maximize their own interest, network maintains fairness among users.

Therefore, we define a traffic management mechanism based on "selfish" users and "fair" network, where the network side is a cloud-based central controller. We use Jain's fairness index to quantify fairness [8], and simulated annealing as a heuristic to solve the optimization problem at the controller side. The Jain's index has been well-used for quantifying fairness in communication networks [9]. At the UE side, the problem of long-term QoS maximization is formulated as a Q-learning problem. The contributions of this paper are threefold:

- We propose a new QoS-based traffic management mechanism which can maximizes QoS utility of each UEs while implementing fairness maximization for the network system. In this paper, we call this scheme QoS and Fairness maximization (QFM). We use Jain's fairness to define fairness among UEs and assume such fairness in maintained at the "central controller". Hence, the final decisions of network selection will be made by both UE and central controller together in order to maximize QoS utility of the UEs as well as Jain's fairness index between all traffic flows.
- We maximize fairness levels of the system with QoS values constraints. It can be implemented by our system model which combines device-controlled mechanism and cloud central controller together. Device-controlled mechanism has been explained in our previous work which is a fully distributed mechanism used to consider UEs' location information and their QoS requirements. In this paper, we add a cloud central controller on top of the whole system and devise an optimization approach to ensure traffic resource has been effectively managed based on our QFM mechanism.
- When backhaul congestion has been taken into account, we can maximize UEs' QoS values by using channels with less congestion. Backhaul congestion tends to decrease the overall system performance and generate unfairness issues among UEs. In this paper, instead of measuring one-way packet delay to detect congested transport backhaul link in LTE networks which has been proposed in existing literature [10], we propose a novel approach using central controller on top of the system to provide information of backhaul links to UEs in the future networks.

The remainder of this paper is organized as follows. Section II briefly reviews the state of art for cloud-based central controller and fairness in traffic management. After elaborating our system model and fairness approach in Section III, our problem formulation and traffic management approach will be described in Section IV and V, respectively. Section VI presents simulation study and performance observations. Finally, highlights of this work and road ahead are discussed in Section VII.

## 2 Related Works

In this section, we review the state of art in cloud-based control plane and also traffic management mechanisms in mobile networks. There is a large body of research on virtualization of mobile network functions and the design of different architecture for cloud-base control plane [10]. Using the SDN paradigm for decoupling data and control and managing network centrally has also been discussed in the 5G literature. Examples of such work are the presented research in [2], [3] and [4]. In [2], new SDN-based architecture for 5G is presented so as to reduce latency for mission critical applications. In [3], it has been shown how logically central controller can be placed in the LTE network architecture. The effect of such architecture design on signalling overhead and agility of control are also discussed in this paper. Furthermore, research work in [4] focuses on the design of access cloud in SDN-based 5G architecture.

On the other hand, the explosive growth of cloud-based applications for mobile devices, brought attention to the development of networking architectures and mechanisms to assist operators in managing traffic as dynamically as possible. Well-designed traffic management will allow network operators to draw maximum value from available capacity by managing network resources as efficiently as possible. Running traffic management at the UEs side allow such decision to be made where the required information are available in the most up-to-date and precise format (all measured at the UE and utilised at the UE). Hence, users can potentially achieve their desired QoS level that is either improving their received data rate, and communication latency or lowering their power consumption. In this regard, the device-centric network architecture has been listed as a solution to address users' stringent QoS requirements in [11]. In [12], automatic Access Network Selection (ANS) has been proposed in a device-controlled manner for better traffic management. Furthermore, various ANS mechanisms for enabling "always-best" connectivity are reviewed in [13], and it has been concluded that introduction of cognition and advanced learning capabilities, can act as a catalyst for improving the quality of ANS decisions. Based on the discussed literature here, we propose a dynamic traffic management mechanism within SDN-based 5G architecture, and with integrating learning capabilities based on the analytics of networks.

Cognition and learning capabilities have been introduced in different aspects of mobile networks including routing, resource management and dynamic channel selection [14], [15]. We use Q-learning in this paper that is a model-free reinforcement learning technique. Q-Learning and reinforcement learning are frequently used in the mobile and wireless networks. An online path selection algorithm based on Q-learning has also been proposed in [16] for minimizing the probability of burst loss in optical switching networks. In [17], fuzzy Q-learning algorithm is used to optimize call dropping rate for traffic steering.

The last topic we touch on, in our background section is consideration of fairness in mobile networks. Fairness has been well-studied in the context of scheduling and wireless recourse allocations, either on the wireless channel or over the end-to-end flow [18, 19]. Similarly fairness has been studied in workload distribution in Datacenters [20]. To quantify fairness, various different fairness measures have been proposed in the literature. The Jain's fairness index [8], which was conceived to measure fairness in computer networks, is a very well used measure of fairness in both wired and wireless networks [21], thanks to its advantageous mathematical properties. Therefore, we also use Jain's index to measure fairness in this paper.

 

# 3 System Model

## 3.1 Model of the system-level architecture

Different elements of our proposed QoS and fairness maximization (QFM) traffic management is detailed in this section, and depicted in Figure 1. The three main layers in this model are the UE layer, the wireless network layer (i.e. radio access and mobile core, e.g. EPC), and the cloud layer (i.e. central controller). These three layers are elaborated here and the flow chart of communication between these layers has been described in Fig 2.

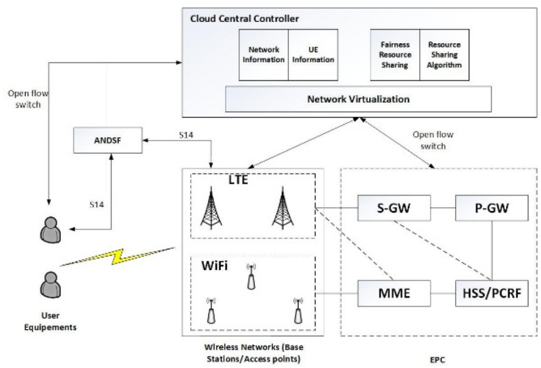


**Figure 1. SDN-based System Architecture.**

- UE Layer: In our model, UEs can communicate with the Access Network Discovery and Selection Function (ANDSF) server via the S14 interface [22]. We further assume ANDSF includes network analytics server and UE can acquire network analytics through S14. The analytics, we consider here, are performance of different RANs in terms of QoS level for the UEs previously connected to the RAN. This information can be collected from database Candidate Networks Information (CNI) which connects with ANDSF directly. The central controller can also communicate with UEs through open interfaces, i.e. the OpenVSwitch on the mobile device operating systems, so that controller's decision on fairness maximization can be communicated to the UEs.

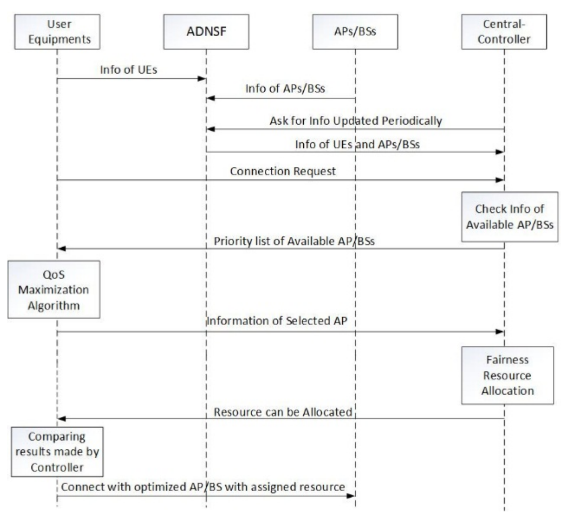


**Figure 2. Communication Architecture**

- Wireless Network Layer: The wireless network layer comprises of the radio access and mobile core network that provide connectivity to UEs. We model the radio access network with four different Access Points (AP), consisting of LTE macro (i = 1), pico (i = 2) and femto (i = 3) as well as one WiFi access point (i = 4). The coverage area of these wireless access points is a circle with diameter $R_i$ meter, where R = {500; 300; 50; 100} (values from [23]). For simplicity, both of the WiFi AP and cellular base stations are referred to as wireless AP from this point on. The core network consists of serving gateway (S-GW), packet data network gateway (P-GW), mobility management element (MME) and policy and charging rules function (PCRF) that have been used to implement connection, mobility and QoS management.
- Cloud Central Controller: Our cloud-based central controller implements the following rules: (1) based on periodically updated information from UEs and APs, central controller can check if any of the AP is available. If only one AP is available for a given UE, controller will assign this AP to the UE; (2) if more than one AP is available for the UE, controller will run fairness maximization algorithm and provide the priority list of available APs to the access network selection at the UE.

### 3.2 UE's battery Models

The UE's battery consumption and how it will be affected by the application's throughput, is modeled here. We use the model described in [27] for the battery discharging rate, $\zeta$, during the lifetime of battery, T, based on Equation (1).

$$\zeta(T) = \frac{\pi^2}{3\beta^2} e^{-\beta^2 T} \tag{1}$$

where $\beta$ is the value of chemical parameter and may vary from battery to battery in the range of (0.4, 1). It has been shown in [28] that by running three different applications concurrently on various smart phones, their battery lasts for two hours. Therefore, T is set to 120 minutes working time is the value we used for our simulations.

The energy consumption of the device, when connected to the *i*-th AP with distance d is detailed in Equation (2).

$$E_i = \zeta(T) + \eta d_i^n \tag{2}$$

where $\eta$ and *n* denote the battery consumption per distance unit, and the propagation loss coefficient, respectively [28].

## 4 Problem Formulation

In this section, we present details of the optimization problems that formulate our proposed QMF mechanism. We will describe two sets of problems, first those who describe the decision making of selfish users and then those that depict fairness maximization at the network. Throughout the problem formulation, we interchangeably use UE and user, assuming each user corresponds to a unique device.

### 4.1 Selfish Users

In our designed traffic management, UEs aim to maximize their QoE. We define QoE as a utility function based on received throughput and the battery consumption, as Equation (3).

$$\Omega = \frac{[\sum_i C_{ij}]^{w_1} + [\sum_i E_{ij}]^{w_2}}{\sum_i C_{ij} + \sum_i E_{ij}} \tag{3}$$

where $C_{ij}$ and $E_{ij}$ represent values of received throughput, and consumed energy by user j = {1, 2, …,U} as a result of connection to the i-th AP, i = {1, 2, …,N}. The first term in the numerator shows the total received throughput by user j, in case this user is connected to multiple APs. Similarly the second term is the total energy consumption at the UE. The $w_1$ and $w_2$ are weight values, representing the significance of these two different criteria in the utility. We further assume that backhaul congestion affects UE's throughput. We model the backhaul link of each AP as a queue with exponentially distributed service time, $1/\mu_i$. Assuming $\sigma_{ij}$ is the received throughput over the wireless channel (using Shannon equation), then the received throughput through the i-th AP is $C_{ij} = \min\{\sigma_{ij}, \mu_i\}$.

To this end, the following optimization problem will be solved at each UE, i.e. $UE_j$.

(P1): Maximize $\Omega_j$

Subject to:

$$\sum_i E_{ij} \le P_j \qquad i = \{1, 2, \dots N\} \tag{4}$$

Where $P_j$ denotes the remaining battery at the j-th UE.

### 4.2 Fair Network

The cloud-based controller aims to maximize fairness among all connected UEs. As explained earlier, we use Jain's fairness index to quantify the achieved fairness among UEs as a result of our proposed traffic management. Jain's fairness index can be explained as:

$$J(X) = \frac{(\sum_{j=1}^{U} x_j)^2}{U * \sum_{j=1}^{U} x_j^2} \tag{5}$$

Where $x_j = \sum_i C_{ij}$, that is the total received throughput by $UE_j$.

Therefore, the optimization problem at cloud-based controller can be formulated as:

(P2): Maximize $J(X)$

Subject to:

$$x_j \ge C_j^{min} \qquad \forall j \in \{1, \dots, U\} \tag{6}$$

Where, $C_j^{min}$ show the QoS requirement (in this case minimum required throughput) of user j depending on its application.

## 5 Traffic Management Solutions

We present different solutions for the proposed traffic management optimizations in section IV. First, we use Q-learning to solve the selfish user optimization problem (P1) and then we use simulated annealing as a metaheuristic to solve the fairness maximization problem (P2).

### 5.1 Solutions to (P1) Using Q-learning

In order to solve (P1) for QoS optimization, we use Q-learning. The main reason for using a learning based approach is the possibility of including historical data so as to make a decision that is optimal choice for longer period of time, and to potentially reduce the number of handovers.

Q-learning is an incremental dynamic planning process, which can be used to determine the optimal strategy through step by step approach. Hence, we need to define time-varying states, actions and reward function for the process of selecting the AP. At each time *t*, *s(t)* describes the state of a given AP, which will alter to *s(t + 1)* by executing action *a(t*). The Q-value of this transition is defined as the expected value in Equation (5).

$$Q^{(t)}(s,a) = E\{R_t | s = s(t), a = a(t)\}. \quad (7)$$

The state *s(t)*, action *a(t)* and reward value of *R(t)* are,

- $s_i(t)$: State of $AP_i$ at time t is denoted by $s_i(t) \in S$ and represent receiving service through $AP_i$.
- $a_i(t)$: Actions $a_i(t) \in A$ represent changing from one AP to another.
- $R_i(t)$: We define the "Reward Function" based on the value of $\Omega$ in Equation (3). Equations (8) and (9) describe the immediate reward, $r_i(t)$, and the weighted and aggregated reward function over time, $R_i(t)$.

$$r_i(t) = \left(\sum_i \Omega_j(t) - \sum_i \Omega_j(t-1)\right), \quad (8)$$

$$R_i(t) = \sum_{k=1}^{10} \gamma^k r_i(t-k), \quad (9)$$

Where $k$ demonstrate number of historical records that are taken into account and $\gamma$ is the discount factor. In other words, $\gamma$ represents significance of the previously recorded reward values on $R_i(t)$. In the simulation study of this paper, we set $\gamma$= 0.995 and the ten time stamps in Equation (9) similar to the described algorithm in [14].

Based on parameters described above, we can calculate Q-values by considering historical records, as follows:

$$Q^{(t)}(s,a) = Q^{(t)}(s,a) + \alpha[R(t) + \gamma Q^{(t)}(s,a) - Q^{(t-1)}(s,a)] \quad (10)$$

where $Q^{(t)}(s,a)$ is the current value of $Q$ for a given AP at time t, and $Q^{(t-1)}(s,a)$ is the historic value that was stored in the CNI and retrieved by the UE. Parameter $\alpha$ represents the learning rate, that is a value in the range of (0, 1), if $\alpha$ = 0, the Q value is never updated. Summary of the Q-learning algorithm for solving (P1) is described in Algorithm 1.

**Algorithm 1:** QoS MAXIMIZATION BASED ON Q-LEARNING

$\sum_j \Omega_j$: total utility value of the $i-th$ AP
$r_i(t)$: immediate reward value at time $t$ of the $i-th$ AP
$R_i(t)$: cumulative reward value at time $t$ of the $i-th$ AP
$Q_i(t)$: cumulative Q value at time $t$ of the $i-th$ AP
$k$: a constant factor defined as $k=100$
$\gamma$: discount rate which reflects the values of importance of rewards
$\alpha$: learning rate and equals to 0.01

1. Initialize Q-values in the matrix for different kinds of networks;
2. Calculate $\sum_j \Omega_j$ for each network;
3. Then, immediate reward value at time $t$ for different networks can be calculated according to the function $r_i(t) = (\sum_i \Omega_j(t) - \sum_i \Omega_j(t-1))$;
4. The cumulative reward function $R_i(t)$ can then defined as $R_i(t) = r_i(t) + \gamma r_i(t-1) + \gamma^2 r_i(t-2) + ... = \sum_{k=1}^{\infty} \gamma^k r_i(t-k)$
5. So, Q-values we are planning to get are received by function $Q_i(t) \leftarrow Q_i(t) + \alpha[R_i(t) + \gamma Q_i(t) - Q_i(t-1)]$
6. Finally, UEs will select the network $i$ with biggest $Q_i(t)$ value at different time steps.

## 5.2 Solution to (P2) using Simulated Annealing

Simulated Annealing (SA) is a well-used heuristic for solving combinatorial problems. At each step of the SA algorithm, current solution will be replaced with a new solution given a certain probability. That probability depends on both difference between the current solution and randomly generated neighbor solution and also the temperature value T of the system [24].

In this section, we describe a solution for (P2) based on simulated annealing algorithm, which runs at the central controller. This algorithm, detailed in Algorithm 2, maximizes achieved fairness among the UEs. We are using Jain's fairness index as explained in IV-B to quantify fairness. Solving (P2), using the SA algorithm to consider maximizing $J(X)$. If the value of $J(X)$ for the neighbor AP is higher than the current one, the algorithm triggers a move to the neighboring AP. Otherwise, the algorithm choose an AP between the current AP and the neighbor AP according to a generated probability value. The random selection will allow solution to converge to global optimal point. The generated probability value for replacing current AP to the neighbor AP is based on $p = \frac{\Delta J(X)}{T}$, where $\Delta J(X)$ shows the difference of J(X) value between the current AP and the neighbor one.

**Algorithm 2:** TRAFFIC MANAGEMENT AT THE CLOUD-BASED CONTROLLER

**Data**:
$J(X)$: Jain's index value;
$T_0$: initial temperature;
$\beta$: temperature decrease rate, where $\beta \in (0,1)$;
$\eta$: change limitation value;

**for** $T := T_0$ to $T_n$ **do**
  Compute current value of Jain's index $J(X)$;
  select neighbour $AP_i$ randomly, and calculate neighbour Jain's index value $J(X)'$ while make sure the value of $x_j$ meets the minimum requirements;
  **if** $J(X)' - J(X) > 0$ **then**
    the $i_{th}$ neighbour $AP$ becomes the current result;
    received throughput value of neighbour $C'_{ij}$ replaces current throughput value $C_{ij}$ as well;
  **end**
  **else**
    generate accept probability $p = \frac{-\Delta J(X)}{T}$;
    then, the $i_{th}$ neighbour $AP$ replaces the current $AP$ based on the probability $p$;
  **end**
  $T_n = \beta * T_{n-1}$, if the fairness index value $J(X)$ is not changed more than $\eta$, then stop.
**end**

# 6 Performance Evaluations

In this section, we explain our simulation settings, discuss, and analyze the results.

## 6.1 Simulation Parameters

As mentioned earlier, we have modeled our system as an integrated wireless network that has four APs: one LTE macro cell, one pico cell and one femto cell, as well as one WiFi access point. We assume coverage areas of the three latter access points are included in the coverage area of the macro cell. The wireless channel is modeled with path loss (see Table I), and hence the RSS can be explained as $RSS_i = TP_i - PL(d_i)$, where $TP_i$ denotes the transmit power of the *i*-th AP, $d_i$ is the distance between UE and the *i*-th AP and $PL(d_i)$ is the associated path loss value [25]. Detailed simulation parameters are described in Table 1.

**Table 1: Simulation Parameters**

| Parameter | | Value |
|---|---|---|
| Peak Data Rate | LTE | 100 Mbps |
| | WiFi | 11 Mbps |
| Tx Power | LTE Macro | 46 dBm |
| | LTE Pico | 23 dBm |
| | LTE femto | 13 dBm |
| | WiFi | 20 dBm |
| Noise Spectral Density | | 128.1+37.6 log(d) |
| Application throughput | Video | 500-700 Kbps |
| | Interactive | 300-600 Kbps |
| | P2P | 700-1000 Kbps |
| | E-service | 600-800 Kbps |
| Cell Coverage | LTE Macro | 500 meter |
| | LTE Pico | 300 meter |
| | LTE femto | 50 meter |
| | WiFi | 100 meter |

## 6.2 Simulation Scenarios

- *Scenario One: QoS-based traffic mechanism:* In this scenario, we examine QoS-based RAN selection without considering history records. Weight values of different criteria have been set as 0.8 for received throughput and 0.2 for consumed energy by UEs, respectively. We assume decisions have been made by the UEs that can communicate with the ANDSF directly in order to receive information of candidate APs as described in 3.1. Therefore, UEs selects the AP that offers highest value of QoS utility, based on Equation (3).

- *Scenario Two: learning-based traffic mechanism:* In this scenario, we examine reinforcement learning based RAN selection. Compared with scenario one, we run Q-learning algorithm at UEs side by considering history Q-values of each available APs. This is based on solving P1 as explained in section 5.1. The main aim of using history values is to reduce the potential number of handovers by selecting the AP that has high performance over a period of time (and not only instantaneously).
- *Scenario Three: QFM-based traffic mechanism:* In this scenario, we examine our proposed QoS and Fairness maximization (QFM) based RAN selection. In scenario three we solve (P1) using Q-learning at the UE side and (P2) at the network controller side. If there exists conflict between the results from the UE side and network controller side, the received throughput values by $UE_j$ should be checked simultaneously. If received throughput values that generated from the network controller side are in the field of application throughput described in Table 1, then the process of selecting APs is based on the results generated from the network controller side. Otherwise, the selected APs are based on the results generated from UE side.

## 6.3 Result Analysis

Our considered Key Performance Indicators (KPI) are: Users' throughput, UEs' battery consumption, number of handovers and Jain's fairness index.

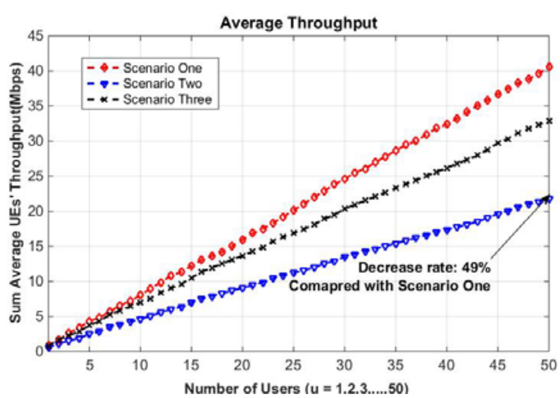


**Figure 4. Sum throughput Vs. number of active users**

Figure 4 indicates aggregated average received throughput for UEs in three different scenarios as we described above. Observing from this figure, it can be seen that throughput values in scenario one are the highest. That is because, the aim of QoS-based traffic mechanism in scenario one is maximizing QoS values based on Equation (3). Maximizing QoS values means maximizing the value of UEs received throughput. Since backhaul congestion are also considered in Scenario one, users were able to connect with an AP that provides higher throughput (and not only higher data rate over the wireless channel). Therefore, the value of sum average throughput UEs received in scenario one is higher than that in scenario two and three.

In scenario two, the sum average UEs' throughput is approximately 50% lower than those of scenario one. That is because, the main aim of learning-based traffic mechanism in this scenario is reducing the potential number of handovers without focusing on improving UEs received throughput. Therefore, the value of throughput in this scenario has decreased dramatically and from this figure not all UEs receive their required throughput values.

In scenario three, it can be explicit shown that the sum average UEs' throughput is lower than that in scenario one but higher than that in scenario two. That is because, the aim of QFM-based traffic mechanism is improving fairness allocation for all UEs which is restricted by achieving minimum UEs required throughput. Therefore, the value of sum throughput should be increased compared with scenario two but still reduced compared with that in scenario one which is mainly focus on maximized throughput values.

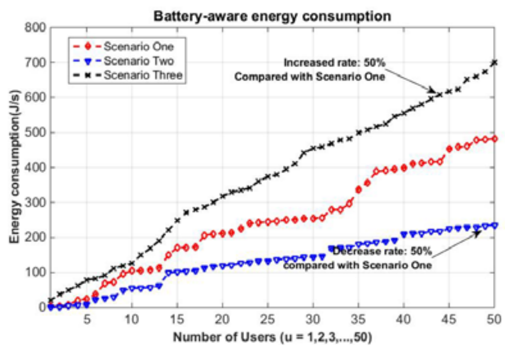


**Figure 6. UEs' average battery consumptions**

Figure 6 shows battery consumption of the UEs in three different scenarios. It can be seen that values of battery consumption in scenario two are the lowest, and those values in scenario three are the highest. Because in scenario two, Q-learning algorithm has been implemented at UEs side. Cumulative reward values can help UEs to learn from history experience of candidate networks and can help them to perform best actions at each time steps. The aim of using Q-learning is reducing number of handovers for all UEs to help them maintain their ongoing communications for longer period of time. Therefore, the value of battery consumption should be reduced in scenario two and it is lower compared with that in the other two scenarios.

Higher battery consumption in scenario three than in scenario one is because the more handover occurred. Based on the Equation (2), device energy consumption is based on the three different variables which are $d$, $\beta$ and $T$. In these three scenarios, values of $\beta$ are the same separately. The more number of handovers, the more time T wasted. From Table 2, the total numbers of handovers are 209, 171 and 257 in these three scenarios separately. Therefore, in Fig 6, decreased and increased values of energy consumption are proportional to scenario one. The more number of handovers generates the more battery consumption.

**Table 2. Total Number of Handovers in each scenario**

| | Scenario One | Scenario Two | Scenario Three |
|---|---|---|---|
| Total number of Handover | 209 | 172 | 257 |

Number of handover over the course of simulation are demonstrated in Fig 7, 8, and 9. It can be seen that average number of handovers in scenario two (Fig 8) is lower than those in scenario one (Fig 7). Reduced number of handovers of UEs can decrease values of battery consumption and confirms the results presented in Fig 6. Higher number of handover can be observed in Fig 9 that correspond to the higher battery consumption of scenario three in Figure 6.

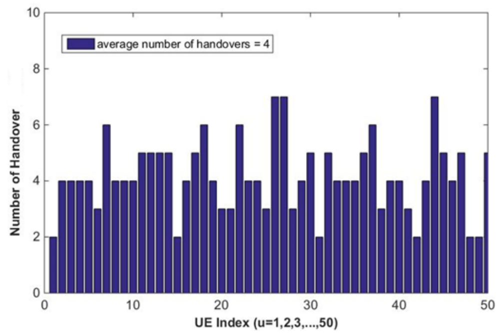


**Figure 7. Number of Handovers in Scenario one (QoS-based)**

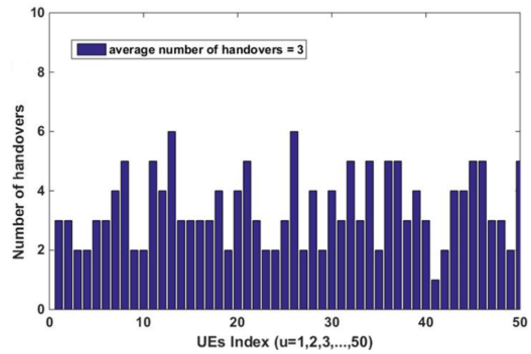


**Figure 8. Number of Handovers in Scenario two (Learning-based)**

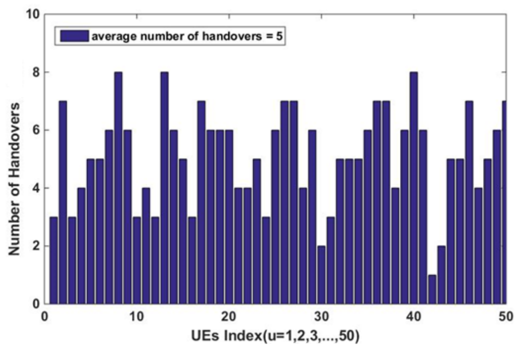


**Figure 9. Number of Handovers in Scenario 3 (QFM-based)**

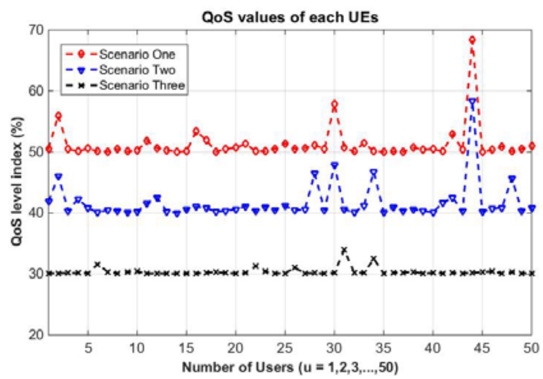


**Figure 10. QoS Utility based on Equation (3)**

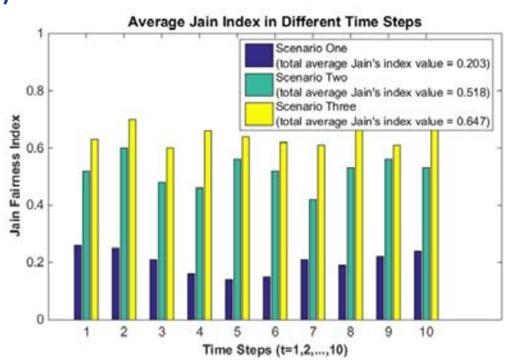


**Figure 11. Average Jain Index in Vs simulation time steps**

Furthermore, Fig 10 shows the QoS utility value (as Equation (3)). It can be seen that the QoS utility is lowest in scenario three and highest in scenario one. That is because, the aim of scenario one is enabling UEs to connect with optimal APs which can provide maximum value of QoS. Based on Equation (3), though the value of energy consumption are higher in scenario one, weight value of it is much smaller compared with throughput which is the main affect factor for QoS level. Therefore, QoS level of scenario two is lower than that in scenario one, even though the energy consumption has been reduced to a large extent. In scenario three, our proposed QFM mechanism implements fairness traffic mechanism which will reduce values of QoS for UEs at the same time. After UEs select APs by considering their selfish requirements, our cloud central controller reassign traffic resource to UEs with respect to fairness.

Finally, Jain's fairness index is plotted in Fig 11. As expected, scenario three has the highest fairness index and scenario one has the lowest fairness index. Based on fairness Equation (5), the value of J(X) is in the field of (0,1) and the higher the better. Higher J(X) value will be generated when values of $(\sum_{j=1}^{U} x_j)^2$ and $(U * \sum_{j=1}^{U} x_j^2)$ are quite similar. In scenario three, fairness problem (P2) has been solved by our proposed QFM mechanism. Network resource has been allocated efficiently while minimum requirements of UEs have been satisfied as well. In scenario one, each UEs purchases higher throughput and connects with the AP which can provide the highest resource at the same time. Therefore, the value of throughput will be quite different between each UEs and it will generate lowest fairness index in scenario one.

# 7 Conclusions

In this paper, we presented a novel approach of traffic management in heterogeneous networks, which is QoS and Fairness Maximization (QFM) mechanism. With the rapid increasing number of mobile devices, their throughput demand and longer battery lifetime requirements, maximizing their QoS levels will be the significant part in the next generation networks. Meanwhile, how to allocate traffic resource in a fairness way is another important issue for us to consider. Our proposed QFM mechanism is composed by two parts which are fully distributed QoS maximization mechanism at UE side and centralized fairness traffic management mechanism at controller side. These two parts are implemented by UEs and cloud central controller separately with the whole view of the system. Based on analysis results, we can find that our proposed fairness problem have been solved. Resources of the network have been fairly allocated and the fairness index has been maximized as well.

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# The Effects of Need Factors and Environment on the Formation of Security Consciousness

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**ABSTRACT**

Educational institutions are taking initiatives in finding a balance between the benefits and dangers of Internet use. However, current curricula for Internet literacy are generalised to feed information and do not serve the individuals. This research aims to develop an educational tool to help each unique individual and will define the link between personal traits (especially the level of needs) and security consciousness.

An online survey was conducted with 2,223 Japanese participants of both genders between the ages of 20 to 79 about their personal need, security consciousness, and the environment. We analysed the data for need factors, safety consciousness, and environment from an exploratory factor analysis. Covariance structure analysis based on the analysed factors clarified the effects of need factors and safety environment on General Security Consciousness and Higher Security Consciousness.

The study found that some need factors facilitate General Security Consciousness, while others hinder it. The data shows that Security Environment had more effect on Higher Security Consciousness than personal attributes.

**Keywords**: Internet Risk, Risk Management, Internet Literacy, Educational Tool

## 1 Introduction

To combat the risks on the Internet, the Japanese government and the Ministry of Internal Affairs and Communications published an Internet Literacy Assessment Indicator for Students (ILAS), which targeted 15-year-old students to measure their ability to utilise the Internet safely and securely [1]. It was due to the OECD Council's adoption of a recommendation in February 2015 and the rapid spread of smartphones, which enabled everyday Internet use among the entire population, especially the youth. We now face the challenge of preparing the population (particularly the youth) with Internet literacy, so they may use the Internet safely and securely.

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In order to safely and securely use online resources, ILAS has defined the following seven points for Internet literacy. These were created based on the risk typologies in the OECD Recommendation [2].

1. Ability to deal appropriately with the illegal and harmful contents on the Internet
   1-a Understand the problems with illegal contents and act accordingly.
   1-b Understand the problems with harmful contents and act accordingly.
2. Ability to communicate properly on the Internet
   2-a Process the information and communicate properly
   2-b Understand the problems with digital transactions and act accordingly
   2-c Consider usage charges and time lost when using the Internet
3. Ability to protect privacy and have proper security measures
   3-a Consider privacy while using the Internet
   3-b Use proper safety measures when utilising the Internet

In 2013 and 2014, the Ministry of Internal Affairs and Communications surveyed elementary, junior high, and high school students as well as their guardians on the literacy levels above.

a) The percentage of correct answers was constant for every guardian age group. For junior high and high school students, the percentage of correct answers decreased as their school ages lowered.
b) There is a higher literacy among those who have received awareness education. Most beginner Internet users have lower literacy and have a higher risk of encountering problems
c) The high literacy population uses the Internet but can moderate their use.

With these results, Teachers, pearents and students are advocating for opportunities to discuss Internet use at home and in schools, as well as limiting the time spent on the Internet. Awareness Workshop for the Young are also advocated, along with providing detailed description of specialised terminologies (i.e., laws and regulations). They also encourage sharing the latest news and information at these workshops for the young and their guardians.

ILAS' survey includes knowledge-based questions such as "You have posted your favourite artist's lyrics on a personal SNS. Choose the best explanations for your action." as the survey also contains ethics questions such as "You heard from your friend that you can get paid by sharing your ID and password online. What is the best way to act in this situation?"

ILAS only targets the youth and their guardians. However, education for Network Literacy is not only for the younger population, as spam emails and frauds target all ages. Workshops and information dissemination are the main measures to raise the Internet security consciousness. However, most problems linked to Networks depend on personal attributes and the environment. School curriculums focus on lecture-style classes. To actualise a dynamic teaching style, the standard of faculty consciousness, skill, and knowledge depends on each faculty and how much effort they put into preparing their classes [3].

This research examines an effects model of network user attribute and environment factor on personal security consciousness, as well as investigating the mechanism of network-related problems. This investigation also opens new doors for developing an education tool that serves each individual, rather than the current interaction-free literacy education.

# 2 Background and Literature Review

## 2.1 Types of Network Problems

The OECD Recommendation has categorised network-related risks as follows.

I. Illegal and harmful information risks
II. Risk of inappropriate use
III. Privacy security risk

Unlawful and damaging risks include being exposed to hate speech, illicit drug trades, and sexual information. The risk of inappropriate use involves purchasing age-restricted products or becoming fraud victims from online shopping. Privacy security risk refers to when personal information is collected or when harmful software is executed without the owner's permission.

According to the reports from the National Police, Ministry of Internal Affairs and Communications, Consumer Affairs Agency and the Media [4], Internet issues can be categorised (see Table 1). Financial problems refer to any problems that arise from online monetary transactions. It is further broken down into categories of criminal cases and uncertain cases between criminal and civil cases.

Communication problems result from unintended online communication. There are two types of communication problems: When the receiver is victimised or becomes involved in a crime and when a sender is criminalised. Management issues include privacy and other information leakages. It is further divided into involuntary malicious leaks or accidental leaks..

Mind-body problems refer to an information tools addiction. There are multiple factors involved in safe Internet use, thus demonstrating a further need to expand the current Internet safety education.

**Table 1 Types of Network Problems**

| Main Category | Minor Category |
|---|---|
| Financial | Fraud, no delivery, stolen/illegal merchandise |
| | Returns, bills |
| Communication | Spam, invitations, false inducement |
| | Cyber-bullying, announcing crimes |
| Management | Illegal information, information leakage |
| | Illegal access, hacking |
| Mind-body | Internet and game addiction |

## 2.2 Relationship between Online Behaviors and Personal Attributes

Studies have already been conducted on the relationship between online behaviours and personal attributes. One studied how receiving education on information morality, user experience in information systems, and social motives is related to the user's level of information morality [5]. From this study, the researchers discovered that further education in information morality resulted in appropriate behaviours when using information systems. A link between daily behavioural motives and decision-making within information systems also became apparent. The study further found the social motives that place importance on order is based on internal standards (e.g., the feeling of shame),_while other social motives that emphasise society is based on external standards such as following rules, not disturbing others, and etiquette.

A study on the relationship between Internet usage and general trust/uncertainty avoidance [6] found that specific Internet services are particularly related to the uncertainty avoidance index (UAI). General trust refers to the feeling of security, while UAI refers to a fear of uncertainty and the unknown. It was concluded from the study that groups with a high general trust and UAI often used SNS; groups with low general confidence and high UAI often used anonymous forums, and groups with great general confidence and low UAI often used online auctions.

Internet addiction is also a rapidly growing issue. Some reports say that just below 10% of Japanese elementary and junior high school students feel restless when they do not have access to mobile phones and games [7]. A study measuring Internet addiction has pointed out that some addicts' excessive Internet use results from their attempt at forming personal relationships.

In another study on the relationship between social skills and problematic online behaviours, users with low social skill tend to seek online interactions. This leads to their uncontrollable Internet use, which had negative impacts on the user. However, there is a report that shows how heavy Internet communication tool use  does not lead to a decline in communication skills, such that it negatively affects the quality of life [9].

# 3 Methods

## 3.1 Participants

An online survey was conducted with 2,223 Japanese participants of both genders between the ages of 20 to 79. The participants were members of an Internet investigation company, and they volunteered to this research with consent. While Internet surveys are cheap and quick, they have issues such as the ambiguity of which social group the collected data belongs to and the influence of factors (e.g., the level of participants' computer literacy and substituted answers). However, the main topic of this study was to investigate Internet usage. Therefore, we do not have to inquire which social group participants belong to as long as they are Internet users. Moreover, research comparing the effects of computer literacy in a mail survey and Internet survey found that there was no significant difference. [13]

In this study, we explained that the survey results will be processed statistically, and will not be analysed to identify an individual. Also, we have specified that the participants do not need to answer any question they do not wish to answer. We additionally told the participants that suspending the answer is allowed. The data obtained from this study are those collected upon the above explanations with the participants' consent and does not conflict any interests.

## 3.2 Period of the survey

The online survey was conducted with consent in November 2015.

## 3.3 Research battery

Question items were made based on the Risk Management Test (RMT) [10] developed by Takeuchi and Suzuki (2000) for providing education on unscrupulous business damage. Forty-five items that guaranteed fixed convergence properties and showed high factor loading on the exploratory factor analysis were used. Also, the questions were structured to elicit information on Internet usage status, trouble experience on the Internet, and the environment, and the consciousness of computer security.

A) Survey item groups on the usage status of cyber-communication: Connected device, used SNS.

B) Risk Management Test (RMT)

RMT is based on Maslow's (1954) hierarchy of needs. It is a test that combines Physiological need, Safety need, Love/ Belonging, Esteem, and Self-actualisation, as well as the Stimulus/Inquisitiveness needs that could increase risk-taker factors in a Risk Management Test (RMT). Participants could answer on a 5-point scale and through self-assessment, such that 1 is "Strongly Disagree" and 5 is "Strongly Agree".

C) Environment and consciousness on security (SAT)

Questions were asked about the environment factors that create security consciousness in computer/network, as well as about the resulting attitude/behaviour. The answer choice ranged from 1 (Strongly Disagree) to 5 (Strongly Agree).

## 3.4 Procedure of Analysis

RMT exploratory factor analysis was conducted to analyse the need characteristics of individual safety. Also, SAT exploratory factor analysis was carried out to analyse the composing factors of the security environment and safety consciousness. For factor analysis, maximum likelihood method was used, and Promax rotations were applied to the obtained results. Factors detected from RMT and SAT were calculated for an individual composite score and were analysed by covariance structure analysis to see the relationship clearly.

# 4 Results

## 4.1 Risk Management Test (RMT) factor analysis

As a result of RMT exploratory factor analysis, seven factors (shown in Table 2) were detected: Pursuit of self-worth, pursuit of purity/virtue, tendency of self-restraint/prioritising others, inclination to conform to external value standards, intent to avoid physical pain, tendency of addiction to superstitions, and pursuit of physical pleasure. Eight factors had eigenvalue over 1. However, factors with only 1 item were considered an anti-convergence factor and were excluded from this analysis.

**Table 2 Results of the Risk Management Test Factor Analysis.**

| | Factor | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Pursuit of self-worth | Pursuit of purity/virtue | Tendency of self-restraint/ prioritising others | Inclination to conform to external value standards | Intent to avoid physical pain | Tendency of addict to superstitions | Pursuit of physical pleasure | Anti-convergence factor |
| | RMT1 | RMT2 | RMT 3 | RMT 4 | RMT 5 | RMT 6 | RMT 7 | 8 |
| I have a desire to complete something "Original" that only you can do | **.701** | .387 | .163 | .100 | -.028 | .150 | .116 | .041 |
| I Want to try something that you have not experienced before | **.696** | .316 | .237 | .216 | -.042 | .228 | .434 | -.075 |
| I Want to be a special person | **.683** | .157 | .159 | .494 | .008 | .321 | .181 | -.115 |
| I am an ambitious person | **.648** | .418 | .102 | .209 | -.254 | .183 | .115 | -.089 |
| I Desire stimulation in life | **.628** | .177 | .190 | .254 | .006 | .259 | .402 | -.059 |
| Do not want to become an "ordinary people", "many others" or a "general public" | **.593** | .304 | .038 | .203 | -.054 | .132 | .097 | -.080 |
| I Tend to like drawing attention from others | **.589** | .052 | .083 | .455 | -.102 | .253 | .185 | -.152 |
| I am a person full of curiosity | **.566** | .494 | .173 | -.051 | -.063 | .092 | .364 | .143 |
| I tend to like dangerous and thrilling activities | **.539** | -.138 | .016 | .442 | -.155 | .195 | .308 | -.360 |
| I Admire a perfect person, and desires to become one | **.434** | .274 | .348 | .376 | .055 | .315 | .208 | -.240 |
| I dislike wrong ways of thinking | .250 | **.776** | .186 | -.183 | .009 | .008 | .046 | .168 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| I strive to become an exemplary person | .176 | **.719** | .272 | -.203 | .036 | .025 | .037 | .335 |
| I cannot forgive when you see something ethically wrong | .251 | **.646** | .173 | -.127 | .060 | .043 | .059 | .261 |
| I make effort to remove contaminant from air/water/food | .196 | **.537** | .285 | -.065 | .145 | .154 | .185 | .267 |
| I admire the pure way of life | .346 | **.503** | .325 | -.001 | .080 | .190 | .153 | .021 |
| I want to do something that is appreciated by others (want to become a person who is appreciated) | .439 | **.493** | .476 | .049 | .008 | .251 | .164 | .098 |
| I love interesting and cheerful things | .356 | **.479** | .257 | -.092 | .127 | .115 | .266 | .454 |
| I have times when I cannot say something, thinking that it might offend the other person | .057 | .181 | **.672** | .003 | .422 | .195 | .208 | .060 |
| I cannot say “No” to something asked | .148 | .337 | **.613** | -.010 | .152 | .207 | .221 | -.014 |
| Sometimes I change my decision by listening to opinions from others | .055 | .031 | **.611** | .251 | .291 | .416 | .349 | -.037 |
| I often endure to make good atmosphere among friends | .186 | .385 | **.601** | -.071 | .180 | .179 | .180 | .087 |
| I often keep silent when I have a different opinion than others | -.041 | -.013 | **.547** | .172 | .329 | .277 | .203 | -.046 |
| I cannot go home alone when my friends are enjoying a party | .182 | .279 | **.541** | .113 | .119 | .270 | .257 | .021 |
| I tend to unconsciously behave in the same manner as others | .035 | -.007 | **.517** | .324 | .235 | .330 | .491 | -.171 |
| I prefer to do anything that would make others happy | .446 | .360 | **.478** | .203 | -.038 | .350 | .243 | -.121 |
| I often decide whether the situation is “Safe” or “Dangerous” by information from others | .130 | .042 | **.440** | .283 | .285 | .288 | .420 | -.136 |
| I use clothes, hairstyle, and make-up that are popular. | .342 | -.154 | .076 | **.746** | -.043 | .342 | .275 | -.378 |
| I feel at ease when I have clothes and accessories that are fine and rich | .260 | -.005 | .251 | **.685** | .054 | .390 | .268 | -.123 |
| I like brand products although they are expensive | .299 | -.053 | .078 | **.610** | -.042 | .302 | .205 | -.149 |
| If I have the chance, I want to become a musician, actor or a talent. | .348 | -.174 | .051 | **.504** | .029 | .259 | .151 | -.291 |
| I feel uneasy when being alone. | .156 | -.118 | .238 | **.397** | .298 | .322 | .199 | -.254 |
| I want to avoid being physically stressed | -.158 | .127 | .199 | -.043 | **.675** | .047 | .145 | .426 |
| I don’t have stamina | -.133 | .026 | .267 | -.093 | **.643** | .069 | .187 | .083 |
| I cannot endure works that are “physically tough” | -.028 | -.033 | .154 | .101 | **.631** | .107 | .135 | .115 |
| My physical strength does not come with my mental. | .071 | .141 | .335 | -.053 | **.586** | .153 | .199 | .007 |
| I do not prefer making myself physically driven to a limit | -.242 | .114 | .210 | -.070 | **.533** | .026 | .093 | .335 |
| I had given up something before due to lack of physical strength which I really wanted to do. | .135 | .091 | .360 | .071 | **.476** | .238 | .202 | -.210 |
| I am attentive to proverbs and superstition that are said to be good for [Safety] and [Auspicious] | .204 | .078 | .378 | .388 | .146 | **.866** | .326 | -.099 |
| I believe in [Amulet] and [Good luck charm] for safety | .225 | .003 | .285 | .406 | .116 | **.744** | .279 | -.179 |
| I avoid foods that are not good for the body and tend to eat foods that are [Good for○○] | .279 | .233 | .334 | .317 | .061 | **.429** | .288 | -.131 |
| I might be easily tempted to delicious food and comfortable things | .309 | .287 | .351 | .108 | .219 | .263 | **.587** | .172 |
| I would like try new activities and foods prior from other people | .498 | .102 | .202 | .499 | -.002 | .328 | **.515** | -.218 |
| I am a type who pursues physical pleasure | .450 | .096 | .255 | .359 | .113 | .351 | **.487** | -.072 |
| I might be selfish to things that are comfortable to myself | .297 | .230 | .233 | .144 | .278 | .236 | **.410** | .121 |
| I want to be rich | .190 | .334 | .261 | -.015 | .280 | .150 | .241 | .414 |
| Percent variance | 17.190 | 9.107 | 7.531 | 3.259 | 2.439 | 1.749 | 1.673 | 1.016 |
| Cumulative percentage | 17.190 | 26.297 | 33.828 | 37.087 | 39.525 | 41.274 | 42.947 | 43.963 |
| Cronbach’s α | 0.853 | 0.797 | 0.799 | 0.723 | 0.760 | 0.698 | 0.663 | |

## 4.2 Factor analysis on the results from the survey about security consciousness and environment

As a result of the SAT exploratory factor analysis, three factors were detected shown in Table 3, namely general security awareness, security environment, and high degree of security awareness.

**Table 3: Factor Analysis Results Regarding Security Awareness and Environment**

| | Factors | | |
|---|---|---|---|
| | General security awareness | Security environment | High degree of security awareness |
| | SS1 | SS2 | SS3 |
| I make sure to check the senders of emails I received before opening them. | **0.753** | 0.159 | 0.128 |
| I make sure to install anti-virus software on my personal computer and smartphone. | **0.663** | 0.145 | 0.118 |
| I make sure to read over what I wrote before sending it as an email or posting it on the Internet. | **0.642** | 0.21 | 0.1 |
| I think it is dangerous to click on the links (URLs) that appear on the posts of bulletin boards. | **0.591** | 0.147 | 0.162 |
| I have received education on computer and computer networks, or I am currently receiving it. | 0.151 | **0.8** | 0.23 |
| I have taken training courses on information morale and security in school or workplace. | 0.158 | **0.774** | 0.188 |
| I sometimes talk about the Internet and computer with people around me. | 0.377 | **0.561** | 0.147 |
| I work on the computer or network-related field. | -0.028 | **0.539** | 0.281 |
| I try to put a lock on my mobile smartphone or normal mobile phone with passwords. | 0.36 | **0.409** | 0.361 |
| I have acquaintances who are well-informed in computer and networks. | 0.259 | **0.368** | 0.177 |
| I regularly change my passwords even before the system prompts me to do so. | 0.23 | 0.261 | **0.742** |
| I always read the licence agreement before installing software. | 0.307 | 0.301 | **0.579** |
| I put a daily limit on how long I use the Internet privately. | -0.043 | 0.148 | **0.5** |
| I do not write down my passwords in memos. | 0.202 | 0.276 | **0.407** |
| I do not do Internet shopping or auctions. | -0.206 | 0.019 | **0.407** |
| I think it is dangerous to input my credit card number on the Internet shopping sites. | 0.262 | 0.001 | **0.341** |
| Percent variance | 25.03 | 11.85 | 9.11 |
| Cumulative percentage | 25.03 | 36.89 | 45.99 |
| Cronbach's α | 0.755 | 0.752 | 0.645 |

## 4.3 Structure of security awareness development

A covariance structure analysis was conducted on the RMT composed scores and the composed scores of security consciousness and environment. This was done to clarity how individual desires and the environment affects participants' Internet literacy. We drew paths from all factors to general security consciousness and higher security consciousness. The path diagram is shown in Fig. 1.

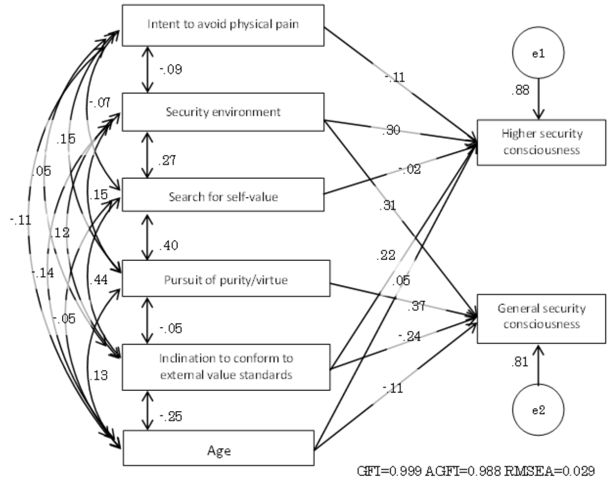


**Figure 1: Relationships between individuals' desire characteristics and security consciousness**

Thus, the "general security consciousness", "pursuit of purity/virtue", "security environment", "age", and "search for self-value" are effective factors, while the "inclination to conform to external value standards" is the obstructive factor.

The goodness of fit index of this model is GFI: 0.999 and AGFI: 0.988, which determines the path diagram is highly explanatory. The index of RMSEA: 0.029 confirms that the model is highly compatible as well.

## 5 Discussions and Conclusion

In this research, we have examined network security consciousness from the individual characteristics and environment affecting network usage. We have verified the survey results by using covariance structure analysis.

Both the"general security awareness" and "high degree of security awareness" factors had a large effect on the security environment. It showed that it was important to have knowledge about security (e.g., having computer or network education, having security related classes or working related to the computer networks).

Against the" general security awareness" and seeing that the" pursuit of purity/virtue" is the largest effective factor, it is conceivable that honesty increases safe consciousness network usage. Also, as " age" is an effective factor, it is conceivable that growing up and maturing can explain for this result. Concerning the results on "inclination to conform to external value standards" being the hindrance to "general security awareness," it shows some individuals have a tendency to be careless and to show off.

We can understand that the security environment and the general security awareness are greatly affect the high degree of security awareness. However, we have to keep in mind that the inclination to conform to external value standards is also an effective factor. A person with a strong inclination to conform to external value standards may generate false correlation, such as a strong orientation for specialised professions. The intent to avoid physical pain is hinders security awareness. Furthermore, selfish behaviour and attitudes or tendencies to dislike putting in effort are thought to prevent individuals from actually utilizing their security consciousness.

By researching the RMT as well as the security consciousness/environment, we have revealed how security consciousness is formed. It is possible to implement a more efficient network literacy education to members entering the Internet environment, where we can warn them before their entry with individualized instructions. By gathering large-scale basic data, we have explored models of psychological/social factors that obstruct risk consciousness and security literacy for members who participate in the network environment. We therefore have to refine these prediction models by gathering more data in the future.

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# Window Based Pulse Shaping Technique for DVB-T System

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**ABSTRACT**

Digital Video Broadcasting (DVB) is an international standard for digital television services. Many versions of DVB are available for commercial use including DVB-H, DVB-S, DVB-C, DVB-T, and DVB-IPTV. In this paper we focus on the performances of DVB-T system. In DVB-T system Orthogonal Frequency Division Multiplexing (OFDM) has been used. The OFDM can minimize Inter Symbol Interference (ISI) and hence it is considered suitable for coping with multipath fading. Like all other OFDM based systems DVB-T signal has some limitations too namely large dynamic range of the signals, sensitivity to frequency error, and high peak to average ratio. It is shown in this paper that the system performance of the DVB-T system highly depends on the pulse shaping filter used in transmitter. Hence, a careful selection of pulse shaping filter is very important for DVB-T system in order to overcome the above mentioned limitations. It is also shown in this paper that the performance of DVB-T system in terms of Bit Error Rate (BER) can be significantly improved provided appropriate pulse shaping filters are chosen.

**Keywords:** DVB-T, OFDM, ISI, transmitter, receiver, filters, pulse shaping, windows, BER, AWGN

## 1 Introduction

Televisions are considered as the most popular electronic devices for entertainment, education, and information. According to the International Telecommunication Union (ITU) the number is TV sets around the World is increasing exponentially (see Fig. 1) and it is expected to reach 700 million by the year 2017 [1]. TV sets were originally developed as an all-electronic system in Europe [2]. Later on a number of color television systems were introduced. Among these systems Sequential Couleur A Memoire (SECAM) and Phase Alternating Line (PAL) became popular. With the advent of digital technology broadcasters and manufacturers started switching analog televisions to digital televisions for two main reasons namely efficient spectrum efficiency and quality of pictures. According to a recent report [1] television sets are now 55% digital. In the developed world 81 percent of total households with a TV that receive digital signal [3] now-a-days.

The idea of Digital Video Broadcasting (DVB) system originated from the need for converting analog television broadcasting system into digital television broadcasting system. The DVB has been a very popular concept dated back to early nineties. Initially, DVB system was introduced to support stationary signal reception by using rooftop antenna. Extensive researches, carried out in Europe as early as 1997, demonstrated that the DVB system also could support signal reception by using portable devices

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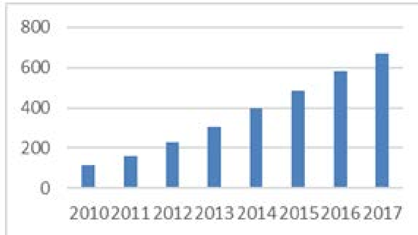
mounted on buses and cars [4]. Since then the DVB system has become a success story in modern broadcasting. The DVB system has drawn considerable attentions of numerous industry-led manufacturers, broadcasters, network operators, and software developers.

Users (in Million)




Year

**Figure 1 Users of TV around the World**

The DVB standard has been introduced, evolved, and maintained by DVB project [5]. Regulatory bodies including European Broadcasting Union, European Committee for Electrotechnical Standardization, and Joint Technical Committee of European Telecommunication Standards Institute are actively involved in the evolution of the DVB system. Many commercial versions of DVB systems are available today. Among these versions DVB-S, DVB-C, and DVB-T are worthwhile to mention here. These versions have been proposed for satellite network, cable networks, and terrestrial networks respectively [6-7]. Some other versions namely DVB-H and DVB-IPTV have been proposed for TV services in handheld devices and Internet Protocol (IP) respectively. In this paper we focus on the DVB-T system.

In DVB-T system the transmitted signal is a Moving Picture Experts Group-Two (MPEG-2) transport system. The DVB-T signal undergoes channel coding and modulation before it is transmitted. In order to enable DVB-T receiver to correct errors a forward error correction (FEC) is used. The DVB-T system has been designed for digital terrestrial television services. It operates within the existing Very High

**Table 1: Comparison of “2K mode” and “8k mode’ [8]**

| **OFDM mode** | | **2K** | | | **8K** | | |
|---|---|---|---|---|---|---|---|
| Number of carriers K | | 1705 (0 .. 1704) | | | 6817 (0 .. 6816) | | |
| **Bandwith of RF channel** | | **6 MHz** | **7 MHz** | **8 MHz** | **6 MHz** | **7 MHz** | **8 MHz** |
| Spacing $K_0$ and $K_{max}$ | | 5,71 MHz | 6,66 MHz | 7,61 MHz | 5,71 MHz | 6,66 MHz | 7,61 MHz |
| Carrier spacing | | 3348 Hz | 3906 Hz | 4464 Hz | 837 Hz | 977 Hz | 1116 Hz |
| Duration $T_{want}$ | | 299 µs | 256 µs | 224 µs | 1195 µs | 1024 µs | 896 µs |
| **Guard Interval** | **1/4** | 75 µs | 64 µs | 56 µs | 299 µs | 256 µs | 224 µs |
| | **1/8** | 37 µs | 32 µs | 28 µs | 149 µs | 128 µs | 112 µs |
| | **1/16** | 19 µs | 16 µs | 14 µs | 75 µs | 64 µs | 56 µs |
| | **1/32** | 9 µs | 8 µs | 7 µs | 37 µs | 32 µs | 28 µs |
| **Carrier modulation** | | **QPSK, 16-QAM, 64-QAM** | | | | | |
| **Inner code rate** | | **1/2, 2/3, 3/4, 5/6, 7/8** | | | | | |

Frequency Band (i.e., 50-230 MHz) and Ultra High Frequency Band (i.e., 470-870 MHz). Two modes of operations have been defined for DVB-T standard namely “2K mode” and “8K mode”. The “2K mode” has been defined for DVB-T transmission and the “8K mode” has been defined for DVB-H transmission [5]. For limited distance transmission the “2K mode” is considered suitable and for long distance transmission the “8K mode” is preferable. Some of the key features and differences between these two modes are listed in Table 1.

The DVB standard allows different levels of Quadrature Amplitude Modulation (QAM) as shown in Table 1 and it uses different inner code rates. The system also allows two levels of hierarchical channel coding and modulation. The basic functional block diagram of DVB standard is shown in Fig. 2. It is shown in the figure that the signal processing functions applied to the input data stream are (i) transport multiplex adaptation, (ii) outer coding, (iii) outer interleaving, (iv) inner coding, (v) inner interleaving, (vi) mapping and modulation, and (vii) OFDM transmission. Most of the signal processing functions as shown in Fig. 2 is done in a digital signal processor. The performance of DVB system highly depends on the modulation as well as the underlying channel conditions. Some basic components of DVB-T system are OFDM, Digital to Analog Converter (D/A), and the front end. In this paper we focus on the digital to analog converter block shown in Figure 2.

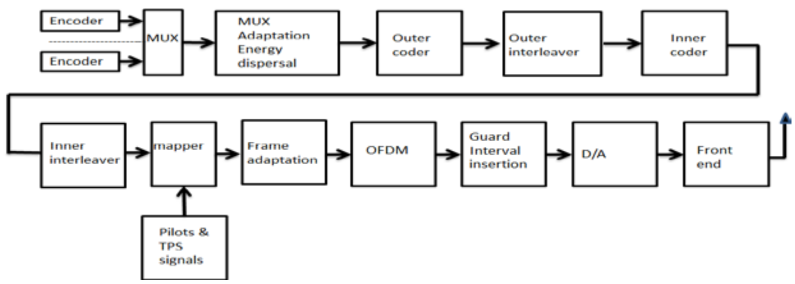



**Figure 2 Block Diagram of DVB system**

The rest of the paper is organized as follows. Some related works have been presented in section 2. The system model used in this work is presented in section 3. The window functions have been described in section 4. The simulation results are presented in section 5. The paper has been concluded with section 6.

## 2 Related Works

It has been proven and accepted that OFDM system supports high data speed transmission in mobile environment. It is considered very suitable for selective fading channel [13, 14]. Other advantages of OFDM system include multi-path delay spread tolerance, immunity to frequency selective fading channels, high spectral efficiency [15,16]. However, OFDM system has disadvantages too. One of them is the sensitivity of OFDM signal against carrier frequency offset which causes ICI [9,10,11,12,13,14,15,16] and another one is the large variation in envelope of OFDM signal, which causes high peak-to-average power ratio (PAPR) [9,10]. Here some of the works that are directly related to our work are presented below.

Pulse shaping of multi carrier signal of OFDM system has been investigated in [17]. Some pulse shapes including Rectangular pulse (REC), Raised cosine pulse (RC), Better than raised cosine pulse (BTRC), Sinc power pulse (SP), and Improved sinc power pulse (ISP) have been considered in [17]. The authors investigated the impulse responses and frequency spectrums of OFDM system for two cases namely without pulse shaping and with pulse shaping. Based on the simulation results the authors concluded that the performance of OFDM system is better with various pulse shapes compared to the same without pulse shape.

In [18] the authors have proposed a semi-blind channel estimation technique for MIMO-OFDM system based on pulse shaping technique**.** The main objective of the work is to reduce the Inter Symbol Interference (ISI). The pulse shaping filter has been realized by a square root raised-cosine filter. By utilizing the knowledge of pulse shaping filters a semi-blind estimation method has been developed. The authors presented some simulation results in the paper. They concluded that the pulse shaping filter has the spectrum with small side lobes. Hence, it leads less Inter Carrier Interference (ICI) and provides better bandwidth efficiency.

A new pulse shaping method for OFDM system called scale alpha has been presented in [19]. In this pulse shaping method alpha is an important parameter and the authors vary the alpha in the range of 0.25 to 1.0. The performance of the OFDM system was compared with other functions namely double-jumped, raised cosine, and Frank pulses. The authors show that the proposed pulse shape performs better than other pulse shapes. The simulated results presented in [19] show that the ICI power can be reduced by almost seven percent by using the scale alpha pulse.

The work presented in [22] is somehow related to our present work. In [20] the authors investigated a number of broadband pulses and narrow band pulses. Mathematical models for each pulse shaping filters have been presented in the work. It has been shown that the square root raised cosine pulse is the best candidate for the OFDM system. It has been shown in [20] that the square root raised cosine pulse not only reduces the peak to average ratio, but also reduces the bit error rate of the system.

Optimized "better-than" raised cosine (BTRC) pulses have been presented in [21] to suppress the ICI effects in OFDM system. The authors came up with some new parameter that follow a quadratic relation with the filter's roll-off factor. The effects of frequency offset have also been addressed by the authors. The simulation results show that BTRC can enhance the performance of the OFDM system in terms of ICI power reduction and Signal to Interference Ratio (SIR).

In our present work we investigate the effects of pulse shaping on the performance of an OFDM system. In this work we choose DVB-T system as our OFDM simulation. In contrast to other related work we focus more on a practical system. We consider a large number of window functions namely Blackman, Blackman-Harris, Gaussian, Hamming, Kaiser, Bohman, Chebyshev, Flattop, Hamming, Hanning, Nuttal, Tukey, Parzewin, Triangle, and Rectangular. These window functions have been widely used in the field of digital signal processing. More specifically these have been widely used in the filter design because of their excellent frequency domain behaviors. In this work we investigated these window functions to improve the performance of DVB-T system.

# 3 System Model

The DVB-T transmitted signals are organized into frame structure. Each frame consists of 68 OFDM symbols [6]. Each symbol consists of a set of K=1705 carriers in the "2K mode" and K=6817 carriers for "8K mode". The transmitted OFDM symbol can be mathematically expressed by

$$s(t) = \mathrm{Re}\left\{ e^{2\pi f_c t} \sum_{m=0}^{\infty} \sum_{l=0}^{67} \sum_{k=K_{\min}}^{K_{\max}} c_{m,l,k} \times \psi_{m,l,k}(t) \right\} \quad (1)$$

Where, $\psi_{m,l,k}(t) = \begin{cases} e^{j2\pi \frac{k'}{T_U}(t - T_G - l\times T_S - 68\times m\times T_S} & (l + 68\times m)\times T_S \le t \le (l + 68\times m + 1) \end{cases}$

$$\psi_{m,l,k}(t) = 0 \quad else$$

where $k$=the carrier number, $l$=the OFDM symbol number, $m$=the frame number, $K$=the number of transmitted carrier, $f_c$= the central frequency, $k'$= the carrier index related to the center frequency, and $c_{m,l,k}$= complex symbol for carrier $k$ of the data symbol number $l$ in frame $m$ . The $c_{m,l,k}$ values are normalized according to the constellation points of the modulation alphabet used.

The transmitter and the receiver models presented in [8] have been used in this investigation. The basic signal processing steps done in the front end of the DVB-T transmitter are shown in Fig. 3. Since the number of carriers in DVB-T system is 1705, we consider 1705 4-QAM symbols as the input data to the transmitter model. We use a bandwidth of 7.61 MHz. We divide the 7.61 MHz into 1705 sub-carriers. We select 4096-point the IFFT for generating the OFDM symbols. The output carriers of IFFT are then converted into a continuous time signal in the next signal processing step. This step of the signal processing is accomplished by using a Digital to Analog (D/A) filter and a low pass filter denoted as pulse shaping filter in the block diagram of Fig. 3. The pulse D/A filter converts the discrete time carrier output signals into continuous signal. In the next step a low pass filter with a sharp bandwidth is used to change the shape of the pulse. We choose a Butterworth filter of order 13 for this purpose. Finally, the carrier modulation is performed at the last stage. These process of converting a discrete signal into continuous signal is illustrated in Fig. 4. The generated output DVB-T signal is shown in Fig. 5. The figure shows that the DVB signal widely varies in amplitude with respect to time.

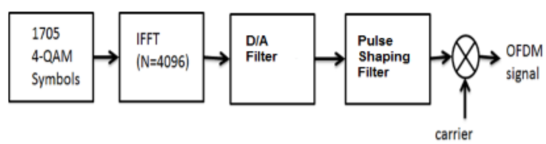



**Figure 3 OFDM Transmitter and Receiver model**

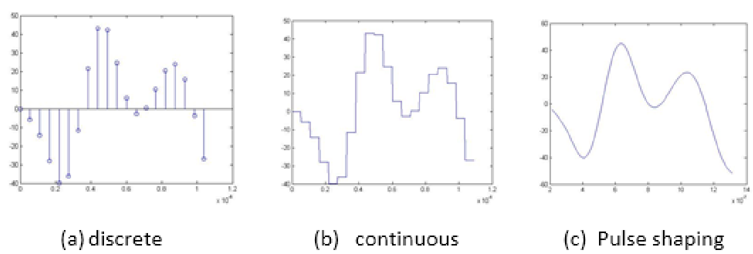



**Figure 4 Converting discrete OFDM symbol into continuous signal**

In this investigation we look for the best D/A filter for DVB-T transmission. Choosing a suitable such filter is import for the DVB-T transmission for the following reasons. The filter has great impact on the power spectral density (PSD) of the DVB-T signal. It helps to produce a compact PSD to reduce Inter Carrier Interference (ICI). It also provides the DBV-T signal with appropriate immunity against noise. Appropriate filter can also reduce the well know problem named high peak to average ratio of the DVB-T signal as shown in Fig. 5. In this investigation we used some popular window functions to change the shape of the DVB-T signals so that the peak to average ration can be reduced and the Bit Error Rate (BER) performance can be improved. The window functions used in this work include Blackman, Blackman-Harris, Gaussian, Hamming, Kaiser, Bohman, Chebyshev, Flattop, Hamming, Hanning, Nuttal, Tukey, Parzewin, Triangle, and Rectangular. The effects on these window functions on the DVB-T system have been investigated in this paper. We primarily investigate the bit error rate (BER) performance of the DVB-T system. We also investigate other effect of pulse shaping filters on DVB-T signal's peak-to-average ratio.

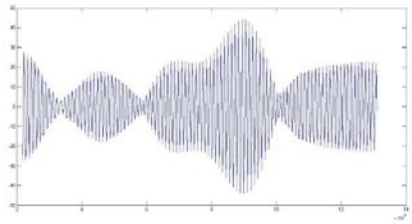


**Figure 5 The variation of DVB-T signal with respect to time**

## 4 Window Functions

Window functions have been used in the signal processing field for a long time. The most popular applications of the window functions can be found in digital filter design. In this work we consider a number window functions for changing the discrete OFDM signal into continuous signal. We consider a number of window functions as listed in Table 2. Although a vast number of window functions can be found in the literatures [22-23], we consider some popular window functions namely Blackman, Blackman-Harris, Gaussian, Hamming, Kaiser, Bohman, Chebyshev, Flattop, Hamming, Hanning, Nuttal, Tukey, Parzewin, and Triangle in this work. The mathematical expressions of the window function are also listed in Table 2. The impulse response, h(n) and the transfer function, H(ω) of each of the window function are shown in Table 3(a) and Table 3(b). Although these window functions have drawn considerable attention of the researchers in the field of digital signal processing for designing filters, we consider these windows for shaping the DVB-T signal so that the performance of the same can be improved.

Observing the frequency domain characteristics depicted in Table 3(a) and Table 3(b) we can make the following conclusions. Some window functions have sidelobes, but other window functions do not have sidelobes. For example, Blackman-Harris, Flattop, Nuttal and Parzewin window functions do not have sidelobes. Although these window functions do not exhibit sidelobes, their spectrums decay very slowly. On the other hand window functions like Hamming, Hanning, Kaiser, Tukey, and Triangle exhibit significant sidelobes. In terms of the magnitude of the sidelobes Hamming, Hanning, Kaiser, Bohman, Tukey, and Triangle windows show larger sidelobes. On the other hand Gaussian and Chebyshev window functions have sidelobes with low magnitude. The frequency domain characteristics of the investigated window functions are summarized in Table 4. This table shows that the window functions also widely differ in terms of the location and magnitude of the sidelobes. For example, in Kaiser window function the location of the first sidelobe occurs at lowest normalized frequency (i.e., 0.40). On the other hand, in Blackman window function produces the first sildelobe at the highest normalized frequency (i.e.,0.75). In terms of the magnitude of the sidelobes Tukey window provides the sidelobe of maximum value (i.e., -20 dB). The Kaiser window and Chebyshev window provides the lowest magnitude sidelobe (i.e., -120 dB).

**Table 2 Window functions**

| Name of Window | Time-domain sequence, $0 \le n \le M-1$ |
|---|---|
| Blackman | $0.45 - 0.5\cos\frac{2\pi n}{M-1} + 0.08\cos\frac{4\pi n}{M-1}$ |
| Blackman-Harris | ,<br>$a_0$=0.35875, $a_1$= 0.48829, $a_2$= 0.14128, $a_2$= 0.01168 |
| Gaussian | $e^{-\frac{1}{2}\left(\alpha\frac{n}{N/2}\right)^2}$ ,α=2.5 |
| Hamming | $0.54 - 0.46\cos\frac{2\pi n}{M-1}$ |
| Kaiser | $\frac{I_0\left[\alpha\sqrt{\left(\frac{M-1}{2}\right)^2 - \left(n - \frac{M-1}{2}\right)^2}\right]}{I_0\left[\alpha\left(\frac{M-1}{2}\right)\right]}$ , α=0.5 |
| Bohman | $\left[1.0 - \frac{\lvert n\rvert}{N/2}\right]\cos\left[\pi\frac{\lvert n\rvert}{N/2}\right] + \frac{1}{\pi}\sin\left[\pi\frac{\lvert n\rvert}{N/2}\right]$ |
| Chebyshev | $\frac{\cos\left[N\cos^{-1}\left[\alpha\cos\left(\frac{n\pi}{N}\right)\right]\right]}{\cosh\left[N\cosh^{-1}\left(10^{\frac{A}{20}}\right)\right]}$ , A=-60dB, α=cosh(1/Ncosh$^{-1}$(10$^{-A/20}$)) |
| Flattop | $a_0 - a_1\cos\left(\frac{2\pi n}{N-1}\right) + a_2\cos\left(\frac{4\pi n}{N-1}\right) - a_3\cos\left(\frac{6\pi n}{N-1}\right) + a_4\cos\left(\frac{8\pi n}{N-1}\right)$<br>$a_0$= 0.21557895, $a_1$= 0.41663158, $a_2$= 0.277263158,$a_3$=0.388, $a_4$=0.028 |
| Hamming | $\alpha - \beta\cos\left(\frac{2\pi n}{N-1}\right)$ α=0.54, β=1-α |
| Hanning | $0.5\left(1 - \cos\frac{2\pi n}{N-1}\right)$ |
| Nuttal | $a_0 - a_1\cos\left(\frac{2\pi n}{N-1}\right) + a_2\cos\left(\frac{4\pi n}{N-1}\right) - a_3\left(\frac{6\pi n}{N-1}\right)$<br>$a_0$= 0.355768, $a_1$=0.487396, $a_2$= 0.144232,$a_3$=0.012604 |
| Tukey | $\begin{cases} \frac{1}{2}\left[\cos\left(\pi\left(\frac{2n}{\alpha(N-1)}\right)\right)\right] & 0\le\alpha\le\alpha(N-1)/2 \\ 1 & \\ \frac{1}{2}\left[\cos\left(\pi\left(\frac{2n}{\alpha(N-1)} - \frac{2}{\alpha} + 1\right)\right)\right] & (N-1)(1-\alpha/2)\le\alpha\le(N-1) \end{cases}$ |
| Parzewin | $\begin{cases} 1 - 6\left(\frac{n/2}{N/2}\right)^2\left(1 - \frac{\lvert n/2\rvert}{N/2}\right) \\ 2\left(1 - \frac{\lvert n/2\rvert}{N/2}\right)^3 \end{cases}$ |
| Triangle | $1 - \left\lvert\frac{n - \frac{N-1}{2}}{N}\right\rvert$ |
| Rectangular | 1 $0 \le n \le N-1$ |

**Table 3 (a): Impulse response and spectrum of different Window functions**

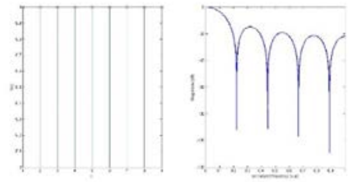
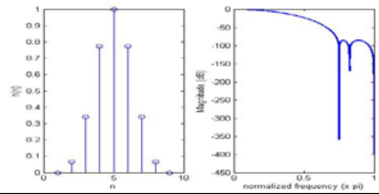
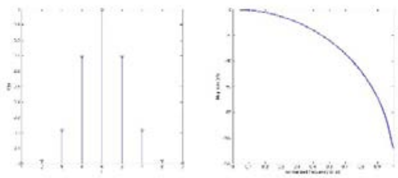
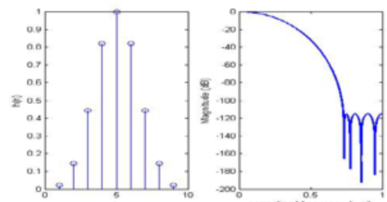
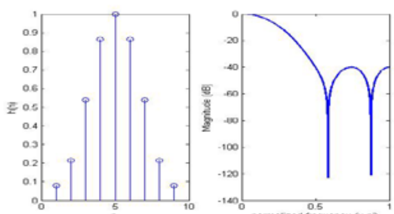
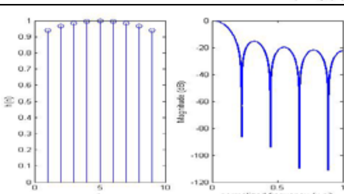
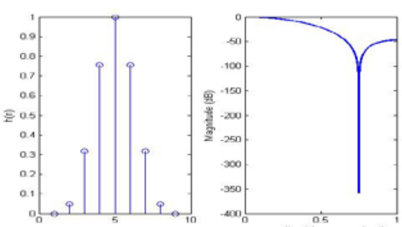
| Name of Window | Impulse Response, h(n) and Spectrum H(ω) |
|---|---|
| Rectangular |  |
| Blackman |  |
| Blackman-Harris |  |
| Gaussian |  |
| Hamming |  |
| Kaiser |  |
| Bohman |  |

**Table 3(b): Impulse response and spectrum of different Window functions**

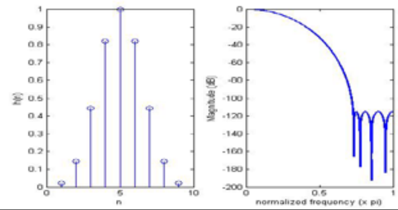
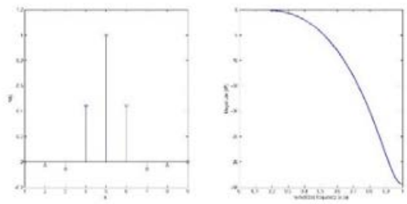
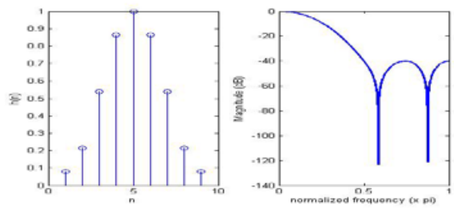
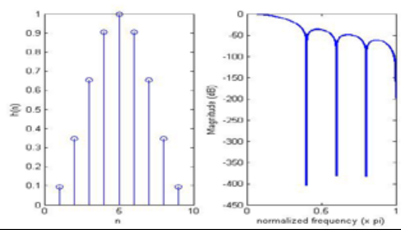
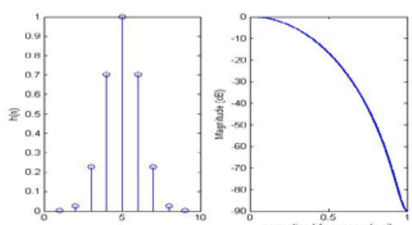
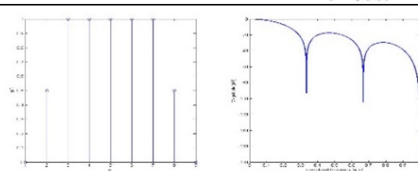
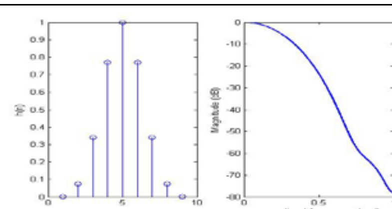
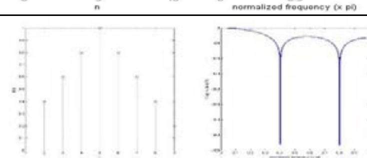
| | |
|---|---|
| Chebyshev |  |
| Flattop |  |
| Hamming |  |
| Hanning |  |
| Nuttal |  |
| Tukey |  |
| Parzewin |  |
| Triangle |  |

**Table 4: Frequency domain characteristics of window functions**

| Window Function | Location of the first side lobe (normalized) | Magnitude of the first side lobes | Location of the main lobe termination (normalized) |
|---|---|---|---|
| Blackman | 0.8 | -100 dB | 0.75 |
| Blackman-Harris | No sidelobe | Not Applicable | Not Applicable |
| Gaussian | 0.75 | -120 dB | 0.7 |
| Hamming | 0.65 | -45 dB | 0.6 |
| Kaiser | 0.4 | -20 dB | 0.25 |
| Bohman | 0.9 | -50 dB | 0.7 |
| Chebyshev | 0.65 | -120 dB | 0.7 |
| Flattop | No sidelobe | Not Applicable | Not Applicable |
| Hanning | 0.5 | -50 dB | 0.48 |
| Nuttal | No Sidelobe | Not Applicable | Not Applicacable |
| Tukey | 0.45 | -20 dB | 0.3 |
| Parzewin | No sidelobe | Not Applicable | Not Applicable |
| Triangle | 0.6 | -40 | 0.4 |

# 5 Simulation Results

The bit error rate of the DVB-T signals for different window functions are shown in Fig. 6(a), Fig. 6(b), and Fig. 6(c). For the clarity of the presentations we splits the simulation results into three figures. Fig.6(a) shows the performances of DVB-T for Hanning, Gaussian, Kaiser, Chebyshev and Blackmann window. This figure shows that Hanning and Kaiser window functions perform the same way and they outperform other window functions namely Chebyshev and Blackmann. Chebyshev window provides the poorest performance.

Figure 6(b) shows the bit error rate performances of DVB-T system for Hamming, Nuttal, Blackman-Harris, Bartlett, and Triangle window functions. It is depicted in Fig.6(b) that Hamming and Triangle windows outperform other window functions. On the other hand the Blackman and Nuttal window functions are not considered suitable for DVB-T system.

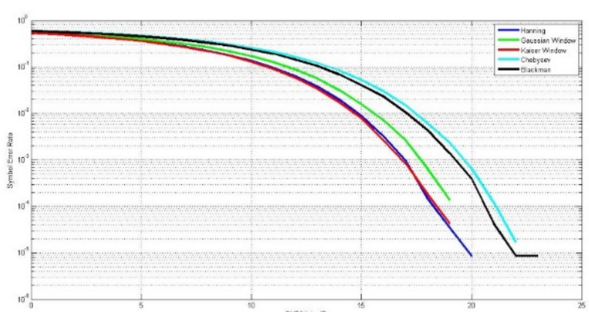



**Figure 6 (a) Bit Error Rate (BER) of window functions part I**

The performances of DVB-T system for Parzewin, Flattop, Tukey, Rectangular, and Bohman are shown in Fig. 6(c). It is depicted in this figure that Tukey and Rectangular window functions perform better than their other four counterparts. Considering all the performances presented in Fig. 6(a), Fig. 6(b) and Fig. 6(c) we conclude that the Rectangular and Tukey window functions are good candidates for pulse shaping filter in DVB-T transmission. Although Hamming and Hanning window demonstrates similar performances, Tukey window and Rectangular window undoubtedly are the best choices for pulse shaping filter in DVB-T transmission.

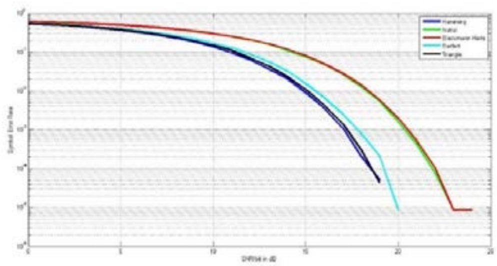


**Figure 6 (b) Bit Error Rate (BER) of window functions part II**

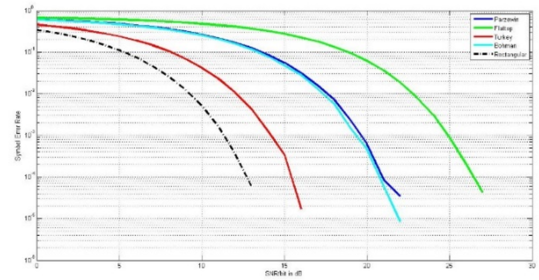


**Figure 6 (c) Bit Error Rate (BER) of window functions part III**

The effects of filters on amplitude variation of the DVB-T signal with respect to time has also been investigated in this work. Table 5 shows the variations in the amplitude of the DVB-T signals for different window functions. This table lists the average value, maximum value, and the ratio of peak to average value for different window functions. It is depicted in this figure that the low value of the peak to average value is achieved by using either the Tukey window or the Rectangular window.

Based on the simulation results we conclude that among the window functions the Rectangular and Tukey window functions exhibit the low BER for a given signal to noise ratio compare to other window functions. Although the frequency spectrum of the rectangular window shows significant sidelobes as shown in Table 3(a) and Table 3(b), but this window functions provide the best performance in terms of BER. The peak to average ratio as listed in Table 5 shows that the rectangular window is the best choice for DVB signal transmission.

**Table 5: The peak-average magnitude of DVB signal for different windows**

| Window | Maximum | Average | Ratio=Maximum/Average |
|---|---|---|---|
| Gaussian | 71.0996 | 5.7223e-005 | 1.2425e+006 |
| Kaiser | 145.7600 | 1.2063e-004 | 1.2083e+006 |
| Blackman | 60.2010 | 4.7999e-005 | 1.2542e+006 |
| Chebysev | 57.3238 | 4.5501e-005 | 1.2598e+006 |
| Hamming | 77.7655 | 6.2517e-005 | 1.2439e+006 |
| Hanning | 78.9959 | 6.3514e-005 | 1.2438e+006 |
| Nuttal | 52.1711 | 4.1278e-005 | 1.2639e+006 |
| Blackmanharris | 51.4438 | 4.0914e-005 | 1.2574e+006 |
| Bartlett | 71.2479 | 5.7457e-005 | 1.2400e+006 |
| Triangle | 75.1570 | 6.0731e-005 | 1.2375e+006 |
| Parzewin | 56.5982 | 4.4847e-005 | 1.2620e+006 |
| Flattopwin | 31.0339 | 2.4270e-005 | 1.2787e+006 |
| Tukeywin | 106.9531 | 8.6690e-005 | 1.2337e+006 |
| Bohman window | 58.1022 | 4.5965e-005 | 1.2641e+006 |
| Rectangular | 148 | 1.2371e-004 | 1.2043e+006 |

We also investigate the performance of DVB-T system by using other popular pulse shaping techniques namely Raised Cosine and Squared Raised Cosine. These pulse shaping techniques have been widely investigated in the literatures [19,20,21]. The BER performance of DVB-T system with Raised Cosine Pulse and Squared Raised Cosine Pulse are illustrated in Fig. 7. These performances have been compared with other window based pulse shaping technique in the same figure. The simulation results show that window based pulse method provides less BER at a given SNR compared to Raised Cosine and Squared Raised Cosine pulses. This simulation results are somehow contrary to the results presented in [19,20,21].

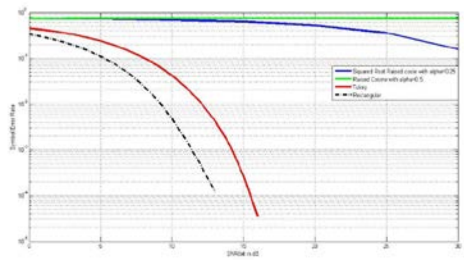


**Figure 7 Comparison of window functions with Raised Cosine function**

# 6 Conclusion

In this paper the effects of pulse shaping filter on the DVB-T system performances have been investigated. It is shown in this paper that pulse shaping filter used in DVB-T signal is an important element. In order to shape the pulses we consider several window functions. The frequency domain and time domain behaviors of the DVB-T signals have been investigated in this paper. The simulation results show that rectangular window function is the best choice for DVB-T signal transmission. Although rectangular functions exhibits some sidelobes in the frequency domain, this window functions provide the best performance in terms of BER and peak-to-average ratio. Moreover, we have shown in this paper that window based pulse shaping filter outperforms other popular pulse shaping techniques namely the Raised Cosine and the Squared Raised Cosine filters.

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# Spectrum Sensing-Energy efficient on Cluster Based Cooperative Cognitive Radio Networks

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**Abstract**

Cooperative Spectrum Sensing (CSS) is one of the proposed solutions to overcome the interference, path loss and shadowing effect. CSS is proposed also to enable secondary users to interact with the primary users by exploiting spatial diversity. However, cooperative sensing is also facing one major issue which is the energy consumption in transmitting the sensing reports to the fusion center especially for a big numbers of cognitive radio users. In this paper, we propose a new cooperative spectrum sensing scheme based on group heads (GHs) where the cognitive users are sorted randomly into groups and the user having the highest SNR of reporting channel will be chosen to be the group head that will be authorized to send its sensing report to the fusion center. In the proposed scheme, only heads of groups are transmitting data to the FC which improves the green energy-saving cognitive communications in cognitive radio network. The simulation results show the high efficacy and efficiency of our scheme.

Index— Cooperative Spectrum Sensing, the energy consumption, secondary users, sensing performance.

## I. INTRODUCTION

Cognitive radio CR is as an intelligent wireless communication system which can exploit the under-utilized spectral resources by reusing unused spectrum in an opportunistic manner [1] [2]. It involves the primary users (PU) and secondary users (SU) [3] intelligently assess to the unused spectrum under license when the primary users are inactive. Secondary users computes the signal strength, interference and the number of users residing in the spectrum and observes the heterogeneous spectrum that varies in time and space due to the activities of primary user [4]. The availability of spectrum depends on the availability of spectrum holes that vary over

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time and location. So, the detection of primary user signals in harsh and noisy surrounding environment presents the most important challenge [5] [6] [3].

Thus, spectrum sensing is considered as a key function for dynamic spectrum access which is designed to maximize spectrum efficiency and capacity within congested wireless transmission environments and it is a critical function to avoid interference with primary users [7] [8]. However, detection performance in practice is often compromised with multipath fading, shadowing and receiver uncertainty issues. To overcome the impact of these issues, cooperative spectrum sensing is proposed as an effective method to improve the detection performance by exploiting spatial diversity [9] [10] [11] [1].

However, even the enhancement of cooperative SU number could improve cooperative diversity gain in cooperative transmission, the cooperation between users has also a big impact on the cost of overhead traffic for control signaling and the result transmission [12], which introduces additional transmission delay and consumes more power and energy which are critical parameters for CRN [9].

In fact, the power resource is limited, especially for battery operated mobile terminals and the and high energy consumption represents a challenge hindering wide implementation of some recent technologies. Many solution have been proposed to solve the energy consumption issue for cooperative spectrum sensing. In [13], the authors proposed the use of hard decision reports in place of sensing reports. In [14], the authors proposed a censorship strategy where only a user that has reliable information can transmit the sensing report to fusion center (FC). However, these solutions are often degraded by multipath and shadowing effect. In [15] the authors proposed a clustering based scheme for spectrum sensing in cognitive radio wireless sensor network, which involves less nodes in spectrum sensing in order to reduce the energy consumption. In [16], the authors presented clustering-based joint compressive sensing which combines the compressive reconstruction technology and hierarchical data-fusion. However, the energy reduction in these schemes is not optimal. In fact, each head cluster has to make a decision based on the local decisions received from its cluster members which means an inter transmission inside the cluster so an increasing on the energy consumption. However, these works focused on the conventional clustering techniques which is not efficient for the energy consumption and the delay transmission.

To solve these issues, in this paper, we propose a cluster and forward based on the highest

SNR. By dividing all the secondary users randomly into clusters and the node having the best channel conditions is chosen as a head group that will transmit its decision to the fusion center. Thus less energy for reporting decision will be consumed with reliable transmission channel, which leads to accurate spectrum sensing.

The main contributions of this paper can be summarized as:

1) Proposing a new scheme for CRN that reduced largely the energy consumption based on grouped Cooperative Spectrum Sensing.
2) Computing the derivation of the maximum channel allocation and the energy consumption of the new scheme.
3) Dynamic head group selection based on the maximum channel allocation.
4) Simulations results have been conducted to evaluate the performance of the proposed scheme.

The rest of this paper is organized as follows. In section II, the system model is presented. The derivation of the maximum channel allocation and energy consumption is presented in section III. The evaluation analysis and the simulation results are given in section IV. Finally, we conclude in section VI

## II. System Model

As shown in Fig.2, the adopted system model consists of one of a Fusion Center (FC) and multiple secondary users (SUs) distributed randomly over $G$ groups. All the SUs are supposed to be equipped with with energy detection which is the most widely-used detection technique. The set of secondary users of is denoted $U_s = \{U_1, U_2, ...U_n\}$. We assume that the primary users do not occupy the entire bandwidth simultaneously, therefore, some of the channels will be available for use by the secondary users.

We assume that the energy detection for local spectrum sensing at secondary users. Hence, each secondary users collects $m$ RSS samples (received signal strength). The sensing report from user $i$ is denoted as $r_i = (r_{i,1}, r_{i,m})$. The test statistic of the energy detector is the average RSS (including the noise power)

$$x_i = \frac{1}{m}\sum_{k=1}^{m} r_{i,k} \tag{1}$$

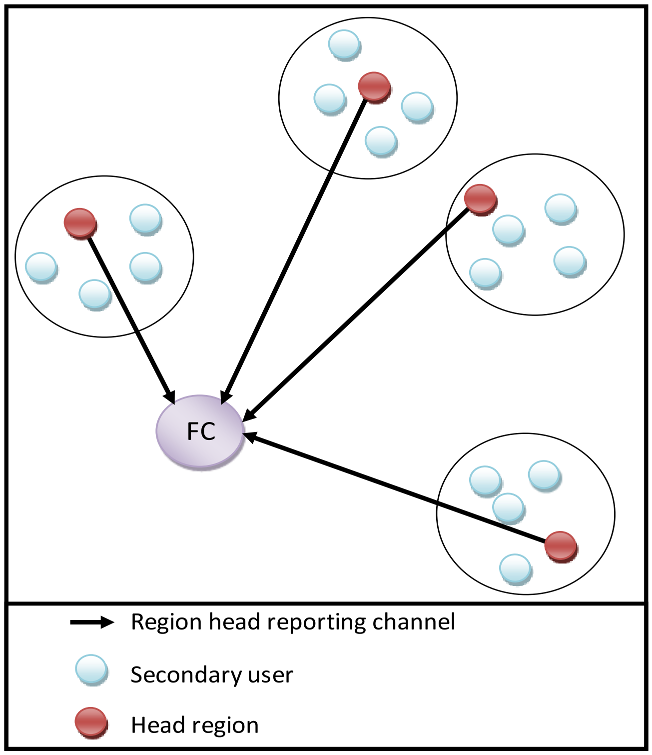


Fig. 1. system architecture

We assume also that the channel between the user $U_i$ in the group $j$ and the primary user denoted $h_{i,j}$ fellows a normal distribution parametrize in terms of the mean and the variance, denoted by $m_{i,j}$ and $s_{i,j}$ respectively.

## III. Best channel allocation and Energy Consumption

### A. Best channel allocation

In this section , we defined the head group based on the maximum channel. In fact, At each group $j$, only one user $i^m$ is selected to transmit the report so that:

$$h_j^m \triangleq h_{i^m,j} = max(h_{i,j})|i = 1..N \tag{2}$$

The probability density PDF of $h_{i,j}$ distribution can be written as:

$$f_{i,j}(x) = \frac{exp(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2})}{\sqrt{2\pi s_{i,j}}} \tag{3}$$

Consequently, its CDF is expressed by

$$F_{i,j}(x) = \int f_{i,j}(x) \tag{4}$$
$$= -\frac{Ei(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2}}{2\sqrt{2\pi}}$$

Where $Ei$ is the exponential integral function.

Hence, the CDF of $h_j^m$ can be expressed by

$$F_j^m(x) = \prod_{i=1}^{N} F_{i,j}(x) \tag{5}$$
$$= \prod_{i=1}^{N} -\frac{Ei(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2}}{2\sqrt{2\pi}}$$
$$\triangleq \prod_{i=1}^{N} k_{i,j}(x) \tag{6}$$

Consequently, the PDF of $h_j^m$ can be expressed by

$$f_j^m(x) = \frac{d\ f_j^m(x)}{dx} \tag{7}$$
$$= \frac{d}{dx}(\prod_{i=1}^{N} k_{i,j}(x))$$
$$= \sum_{i=1}^{N} g_1^i h_1^i$$

where

$$g_1^i = \frac{d}{dx}(k_{i,j}(x)) \tag{8}$$
$$= \frac{exp(-\frac{(x-m_{i,j})^2}{2s_{i,j}^2})}{\sqrt{2\pi}(x-m_{i,j})}$$

and

$$h_1^i = \frac{1}{k_{i,j}(x)} \prod_{i=1}^{N} k_{i,j}(x) \tag{9}$$

Consequently and from 9, we deduce that $P(x_i|H_1)$ can be expressed as follows:

$$P(x_i = z|H_1) = \int \frac{f_j^m(\frac{x}{s})}{|s|} l_N(z-x)\ dx \tag{10}$$

where $l_N$ denotes the probability density function of the noise which can be expressed as follows

$$l_N(x) = \frac{exp(-\frac{x^2}{2N_0})}{\sqrt{2\pi\sqrt{N_0}}} \tag{11}$$

where $N_0$ denotes the noise spectral density. Note that the expression in 11 is very complicated and cannot be computed mathematically hence for the simulation, it is evaluated using the trapezoidal numerical integration method.

## *B. Energy and Power Consumption:*

In general, the energy dissipation $E_{dp}$for a user $U_i$ is the sum of the power amplifier and the energy dissipated for the transmission $E_{tx}$, and $E_{rx}$ which is the receiving energy dissipation. Thus, for transmitting or receiving a message having $L$ bits over a transmission distance $D$, the can be expressed as:

$$E_i^{tx} = \begin{cases} LE_i^{elec} + L\epsilon_{fs}D^2 & D > D_0 \\ LE_i^{elec} + L\epsilon_{mp}D^4 & D < D_0 \end{cases} \tag{12}$$

$$E_i^{rx} = LE_i^{elec} \tag{13}$$

Where $E_i^{elec}$ is the electronic energy consumed in recieving or transmitting data in $U_i$. $\epsilon_{fs}$ and $\epsilon_{mp}$ are the dissipated energy and the power amplifier to maintain an acceptable SNR for reliable data transfer. They depend on the channel model, where $R^2$ is the free space path loss, and $R^4$ is the multipath fading loss. We denote by $D_0$ the threshold distance [14] and it can be written as:

$$D_0 = \frac{\epsilon_{fs}}{\epsilon_{mp}} \tag{14}$$

For the energy consumption during $E_{cp}$ the sensing period. It is the sum of $(E_s)$ which is the energy consumed for the sensing of the channel occupancy and $(E_c)$ which is the energy consumed for the computation of observations and generating the local decision ; $(E_p)$ is the energy consumed in the sleeping mode ; and the energy consumed in sensing the local decision to the fusion center $(E_r)$.

In general, $E_p < E_c << E_r$, then $E_p$ and $E_c$ are ignored. Under these considerations, the energy consumption of a secondary user $SU_i$ can be calculated as follows:

$$E_i^{cp} = E_i^s + E_i^r \tag{15}$$

Hence, if we assume that the FC is far from the secondary users, hence the energy dissipation for the $SU_i$ follows the multipath model ($R^4$ power loss) and it can be written as:

$$E_i^{tx} = LE_i^{elec} + L\epsilon_{mp}D^4 D < D_0 \tag{16}$$

The total energy for CRs noted $E_{TE}$ in its classical form is an increasing function of number of users ($M$) and it can be calculated as follows:

$$\begin{aligned} E_{TE} &= \sum_{i=1}^{M} (E_i^{cp} + E_i^{rx} + E_i^{tx}) \\ &= \sum_{i=1}^{M} (E_i^{s} + E_i^{r} + L(2 \times E_i^{elec} + \epsilon_{mp}D^4)) \end{aligned} \tag{17}$$

Hence and since the number of secondary users transmitting messages to the FC is reduced largely and only the group heads are transmitting data to the FC. So, if we denote by $E_{TGroup}$ the total energy of $G$ groups of secondary users, $E_{TGroup}$ can be written as:

$$E_{TGroup} = \sum_{i=1}^{G} (E_i^{s} + E_i^{r} + L(2 \times E_i^{elec} + \epsilon_{mp}D^4)) \tag{18}$$

So, if we note by $R_{reduction}$ is the energy reduction between the traditional model and the proposed scheme and according to eq.18and eq.17 , we have:

$$\begin{aligned} R_{reduction} &= \frac{E_{TE} - E_{TGroup}}{E_{TE}} \\ &= \frac{\sum_{i=1}^{M} (E_i^{s} + E_i^{r} + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^{s} + E_i^{r} + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \\ &\quad - \frac{\sum_{j=1}^{G} (E_j^{s} + E_j^{r} + L(2 \times E_j^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^{s} + E_i^{r} + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \\ &= 1 - \frac{\sum_{j=1}^{G} (E_j^{s} + E_j^{r} + L(2 \times E_j^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^{s} + E_i^{r} + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \\ &= 1 - \delta \end{aligned} \tag{19}$$

where

$$\delta = \frac{\sum_{j=1}^{G} (E_j^{s} + E_j^{r} + L(2 \times E_j^{elec} + \epsilon_{mp}D^4))}{\sum_{i=1}^{M} (E_i^{s} + E_i^{r} + L(2 \times E_i^{elec} + \epsilon_{mp}D^4))} \tag{20}$$

or

$$G <<< M \tag{21}$$

$$\tag{22}$$

So

$$1 - \delta >> 0$$

$$R_{reduction} >> 0 \tag{24}$$

$R_{reduction}$ is always bigger than 1 which proves that the proposed scheme can significantly reduce energy consumption compared to the classical system by involving only one node in a cluster which is the head group for sending the sensing report to the fusion center instead of all.

## IV. SEQUENTIAL PROBABILITY RATIO TEST

After receiving the sensing reports from the group head of each group, the FC applies the Sequential Probability Ratio Test (SPRT) technique [17]. The probability ratio $V$ is generated as:

$$V = \ln(\frac{P(x_i|H_1)}{P(x_i|H_0)})^2 \tag{25}$$

Where $P(x|H_k)$ presents the probability density function of the received signal $x$ from the group heads under $H_k$ (k=0 or 1).

The FC decision is defined as:

$$V \geq A \Longrightarrow \text{Accept } H_1 \tag{26}$$

$$V \leq B \Longrightarrow \text{Accept } H_0$$

$$A < V < B$$

$$\Longrightarrow \text{Aggregate an additional report from an other head group.}$$

Where $A$ and $B$ present the thresholds computed respectively based on the desired miss detection probability $\eta$ and false alarm probability $\phi$.

According to [11] $A$ and $B$ can be written as follow:

$$A = \ln(\frac{1-\eta}{\phi}) \tag{27}$$

$$B = \ln(\frac{\eta}{1-\phi}) \tag{28}$$

At each iteration, the FC makes the addition of the received sensing reports of the head group. Then, it computes $V$ based on Eq.27 and controls if the final decision is reached or not. However, if the decision is not reached after aggregating all the sensing decisions of the cluster heads, the FC considered that the PU is transmitting to avoid interference. In the end, we update the reputation profile for each user.

## V. Simulations

An IEEE 802.22 WRAN environment with three DTV transmitters is considered. the secondary users are in a range of 1 to 2km. We assume that the total number of users is 100. $\phi = 0.01$ is the desired miss detection probability and $\eta = 0.1$ is the desired false alarm probability.

Fig.2 shows the miss detection probabilities of the proposed scheme as a function of the SNR. We can see that the miss detection probability increases with low SNR which proves that the proposed model is enable to transmit the sensing report to the FC with high level of nose. In addition, it can be seen that the miss detection probability is close to $0$ and does not exceed $0.1$ when the SNR between $20$ and $25$dB.

We notice that when the number of groups increases the miss detection probability deceases which improves the system performance. In fact, for a small number of groups we have small number of group heads, so there is high probability to make a wrong decision. Fig.3 shows the false alarm probability of the proposed model as a function of the number of malicious users. It can be seen that also in terms of false alarm probability; our scheme loses its performance when SNR $= 0$ and it reaches $0.1$ for SNR between $15$ and $25$ dB. We can remark that when the number of groups increases the false alarm probability deceases which improve the system performance. In fact, for a big number of groups we have big number of group heads, so there is high probability to make a good decision. Compared to the miss-detection probability presented in 2, the false alarm probability is more sensitive to the SNR since in case where the FC cannot be sure if the primary user is using the spectrum or not it assumes that there is a

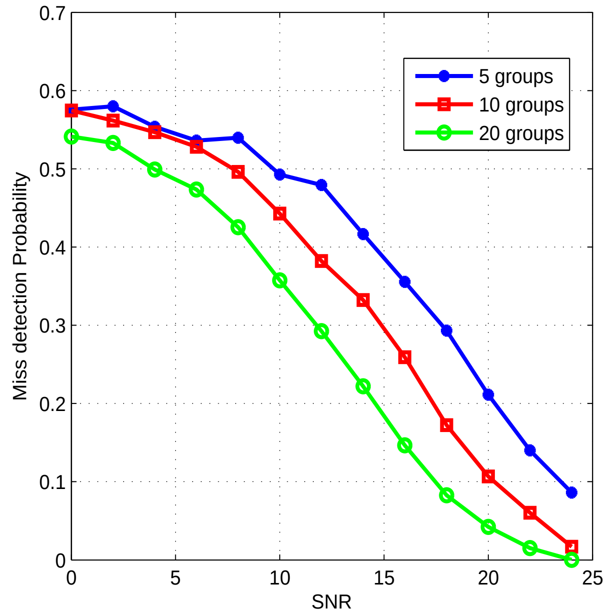


Fig. 2. Miss detection Probability Vs SNR

transmission to prevent possible interferences which may increase the false alarm probability in case of uncertainty.

## VI. Conclusions

In this paper, we proposed a novel scheme for cooperative spectrum sensing based on groups partition and dynamic head group selection. The new scheme improves the spectrum sensing by reducing largely the energy consumption compared to the conventional model.Analytical results showed that the proposed scheme reduced the power consumption compared the conventional model and the simulations results show that for big number of groups, the system is able to make an accurate decisions while reducing miss detection and false alarm probabilities.

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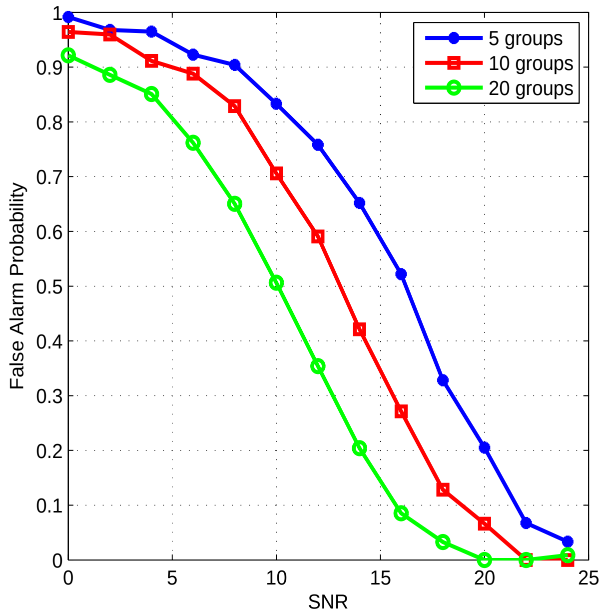


Fig. 3. False Alarm Probability Vs SNR

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