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民生網路之前瞻研究--子計劃五:多標準共存之可調無線介接與正交分頻(1/2)

期中進度報告(完整版)

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行政院國家科學委員會補助專題研究計畫 □ 成 果 報 告
■期中進度報告

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計畫主持人：陳光禎 教授
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目　錄

中文摘要

在這民生網路子計畫中，我們對民生網路（Consumer networks）的定義為，它必需能夠處理操作在同一個頻帶的多種不同通訊標準，包括在同一個裝置或在電波接受範圍之內的通訊環境。而在多種具有潛力的無線網路標準中，正交分頻多工無線區域網路系統（OFDM WLAN）、WiMAX 無線技術、以及使用多頻帶正交多頻分工（Multi-band OFDM）之超寬頻系統（UWB）被選為討論的對象。

因為這些系統都架構在正交分頻多工技術上，所以有必要針對影響系統效能的不理想特性作分析。相位雜訊在正交分頻多工技術中是一個主要的議題。本期計畫中，我們建立了相位雜訊的模型，並在正交分頻多工或是正交分頻多工多重存取的上行鏈路環境中估測相位雜訊。

此外，對於我們所提出之民生網路系統架構中之連結層作了探討。多個具有無線網路聯結功能的終端設備，在沒有基礎建設的情況下，其間可能建立無線隨意網路。而在無線隨意網路裡的節點通常會被要求以最小的功率來傳送資料，同時又要顧到傳送距離來達到網路之連通性。為了以更具功率效率的方法來控制網路拓撲架構，我們探討在無線隨意網路中之最佳傳送距離(或發射功率)、服務範圍的大小以及網路連通性三者彼此之間的關係。

關鍵字：民生網路，正交分頻多工，多頻帶正交多頻分工，相位雜訊，無線隨意網路，拓撲控制，叢集演算法。

英文摘要

In the project of Consumer networks, the term “”consumer networks” is promised to deal with multiple standards operating in the same frequency band, either within the same device or with a radio range. Among many potential wireless networks standards, OFDM WLAN, WiMAX, and UWB using multi-band OFDM are selected to be discussed.

Because that these three systems are based on OFDM technique, there is a need to analyze the non-ideal characteristics of such technique. Phase noise is the main issue in OFDM technique. In this subproject we build up the model of phase noise and estimate the phase noise in uplink OFDM/OFDMA.

Besides, we discuss the connectivity layer of system architecture for consumer networks. Plenty terminal equipments capable of wireless connectivity may construct wireless ad hoc networks under the situation of none infrastructure. Nodes in the wireless ad hoc networks are required to conserve the limited battery life with minimized transmission power. In addition, the wireless ad hoc networks are required to be connected. In order to control the topology structure in a power-efficient way, the discussion on relationships of the best transmission distance (or transmission power), the coverage of the service and network connectivity is given.

Keywords: Consumer network, OFDM, OFDMA, Phase Noise, Wireless Ad Hoc Networks, Topology Control, Cluster Algorithm.

前言

Part I Phase Noise Estimation in OFDM and OFDMA Uplink Communications

OFDM transmission technique has been adopted in several wireless communication standards for its capability of combating channel multipath fading with relatively low complexity while providing high spectral efficiency in comparison to single carrier transmission. An OFDMA system divides the available subcarriers into groups, called subchannels, and assigns one or multiple subchannels to multiple users for simultaneous transmission. OFDM is tremendously more sensitive to carrier frequency offset and phase noise than single carrier systems because the orthogonalities among OFDM subcarriers will be destroyed so that common phase error (CPE) and inter-carrier interference (ICI) will appear. OFDMA inherits from OFDM the weakness of being more sensitive to both of them than single carrier multiple access systems. Furthermore, because of the multiple phase noise of multiuser, phase noise will be more detrimental to uplink OFDMA systems if not carefully compensated

Part II Characterizing The Wireless Ad Hoc Networks by Using The Distance

Distributions

Wireless ad hoc network has been recognized as one of the possible solutions to realize the dream of pervasive computing especially when nodes are within the *dead zone*, an area where the exiting fixed infrastructures are unavailable, since nodes in the wireless ad hoc network can self-organize and operate without the help of the existing infrastructures. By using the multihop forwarding scheme, nodes in the wireless ad hoc networks exchange messages with other nodes that are not directly connected. However, due to the random deployment of the wireless ad hoc networks, the deployed network topologies are also random. As a result, some criterions are commonly used to characterize the random organized network.

Part III On The Distance Distributions of The Wireless Ad Hoc Networks

Since nodes in wireless ad hoc networks may be randomly and independently spread over the entire service area, the resulting network topologies are diverse and, thus, the separation distance between any selected node pair can be regarded as a random variable. Many characteristics of the wireless ad hoc networks are related to the separation distances between node pairs. One of the most important characteristics for the wireless ad hoc network to be applicable is the connectivity of the organized network. The most common approach to achieve the network connectivity is to maximize the transmission range so that nodes are connected. However, when the power consumption is considered, the transmission range should be optimized to the separation distance to its nearest neighbor.

Part IV Organizing an Optimal Cluster-Based Ad Hoc Network Architecture by the

Modified Quine-McCluskey Algorithm

When wireless nodes are in an area that is not covered by any existing infrastructure, one of the possible solutions to achieve the ubiquitous computing is to enable wireless nodes to operate in the ad hoc mode and selforganize themselves into a cluster-based network architecture. One of the general approaches to build up a cluster-based network architecture is to design an algorithm to organize wireless nodes into set of clusters. Within each cluster, a node is elected as a *clusterhead* (CH) to take responsible for the resource assignments and cluster maintenances. Many related algorithms have been proposed. The *minimum connected dominating set* (MCDS) approach tries to obtain an optimum configuration to be the virtual backbone of the wireless ad hoc networks. However, it is shown to be an NPhard problem. The most feasible alternative is to find an approximated heuristic algorithm to obtain a sub minimum connected dominating set. The general idea among the related literatures is to select CHs based on some attributes of the networks.

Part V A Clustering Algorithm to Produce Power-Efficient Architecture for (N,B)-Connected Ad Hoc Networks

Wireless ad hoc network is a self-organizing network that can be rapidly deployed and operated without the help of the existing infrastructure. Possible examples of the wireless ad hoc networks can be found in the tactical military applications, disaster recovery operations, exhibitions and conferences. Since there is no existing fixed infrastructure in the wireless ad hoc network, organizing the randomly deployed nodes into a virtual backbone turns out to be an important design issue. One of the general approaches is to organize nodes into groups of clusters. Within each cluster, a node is elected as the local controller of that cluster and is called clusterhead (CH). Major advantages of this approach include frequency spatial reuse, smaller interference and the increase of system capacity.

研究目的

Part I Phase Noise Estimation in OFDM and OFDMA Uplink Communications

Phase noise issue is an important topic in OFDM and OFDMA systems because it will destroy the orthogonalities among subcarriers. Models of phase noise source and the corresponding effects in OFDM systems are first introduced. There are various methods proposed to suppress phase noise in OFDM systems. Here, we discuss a pilot-aided-decision-directed (PADD) approach for CPE estimation in OFDM systems. Conventional phase noise correction methods targeting at single phase noise, however, cannot be directly applied to uplink OFDMA transmissions because simultaneous transmitted user signals give rise to multiple phase noise. Extending from the PADD approach, two algorithms based on least-square and maximum likelihood criteria for estimation of Wiener phase noise in uplink OFDMA communications are discussed and compared.

Part II Characterizing The Wireless Ad Hoc Networks by Using The Distance

Distributions

Due to random deployment of the network nodes, the distances between nodes in the wireless ad hoc networks are random. Based on the developed distributions of the distance between nodes, the optimum transmission range to the *k*-th nearest neighbor, the most probable distance between two randomly selected nodes, the node degree and the network connectivity of the organized wireless ad hoc networks both in the ideal and shadow fading environments are characterized and evaluated. In addition, we also mathematically proof that the distribution of the node degree in the shadow fading environment is binomial. We apply the derived degree distribution to study the generalized *k*-connectivity problem of the wireless ad hoc network in the shadow fading environments.

Part III On The Distance Distributions of The Wireless Ad Hoc Networks

Separation distance between nodes is an important index in characterizing the optimum transmission range, the most probable Euclidean distance between two random selected nodes, the node degree and the network connectivity of wireless ad hoc networks. However, because nodes are randomly deployed, the separation distances between nodes in the wireless ad hoc networks are also random. Thus, in this paper, we present methodologies to analyze three distance-related probability distributions: the distribution of the distance to the k-th nearest neighbor, the distribution of the distance between two random selected nodes and the joint distribution of the distances between nodes and a common reference node.

Part IV Organizing an Optimal Cluster-Based Ad Hoc Network Architecture by the

Modified Quine-McCluskey Algorithm

An optimal cluster-based ad hoc network architecture that requires the minimum number of cluster maintenance overheads not only reduces the waste of the precious bandwidth but also saves the consumption of the limited battery power. Mathematical analyses show that the cluster maintenance overheads can be minimized by minimizing the number of generated clusters and the variance of the number of cluster members. By using the Modified Quine-McCluskey (MQM) algorithm, the number of generated clusters and the variance of the number of cluster members of the generated cluster-based network architecture are minimized. Thus, the number of overheads required to maintain the cluster architecture is minimized and the precious bandwidth and the limited battery power are saved.

Part V A Clustering Algorithm to Produce Power-Efficient Architecture for

(N,B)-Connected Ad Hoc Networks

Reducing the waste of the limited battery power in exchanging cluster maintenance messages is one of the important issues in designing clustering algorithm for the wireless ad hoc networks. Analyses show that this can be achieved by reducing the number of generated clusters and the variance of the number of cluster members. By assigning critical node (the only neighbor of boundary node) the highest weight (or priority) to be selected as a clusterhead, we show that the number of cluster maintenance overheads is reduced by the proposed Distributed Clustering Algorithm with Critical Node First (DCA/CNF) based approaches. As a consequence, the limited battery power is conserved and the organized network architecture is power efficient.

研究方法

Part I Phase Noise Estimation in OFDM and OFDMA Uplink Communications

OFDM transmission technique has been adopted in several wireless communication standards for its capability of combating channel multipath fading with relatively low complexity while providing high spectral efficiency in comparison to single carrier transmission. An OFDMA system divides the available subcarriers into groups, called subchannels, and assigns one or multiple subchannels to multiple users for simultaneous transmission. Signals from different users are overlapping in frequency domain but occupying different subcarriers, the orthogonality among subcarriers prevents multiple access interference (MAI) among users.

On the other hand, OFDM is tremendously more sensitive to carrier frequency offset and phase noise than single carrier systems [1] because the orthogonalities among OFDM subcarriers will be destroyed so that common phase error (CPE) and inter-carrier interference (ICI) will appear. OFDMA inherits from OFDM the weakness of being more sensitive to both of them than single carrier multiple access systems. Furthermore, because of the multiple phase noise of multiuser, phase noise will be more detrimental to uplink OFDMA systems if not carefully compensated [2].

Various methods to suppress phase noise in OFDM systems have been proposed in the literature [3]-[5]. However, they are specifically suitable for dealing with single phase noise. To mitigate multiple phase noise in OFDMA uplink, unavoidably, the adopted subcarrier assignment scheme needs to be taken into account since it affects the amount of MAI in the system. Two major subcarrier assignment schemes: subband-based and interleaved [6] are examined. The former divides the whole bandwidth into small continuous subbands, each user is assigned to one or several subbands. In the latter, subcarriers assigned to different users are interleaved over the whole bandwidth. An example of both schemes is illustrated in Fig. 1.

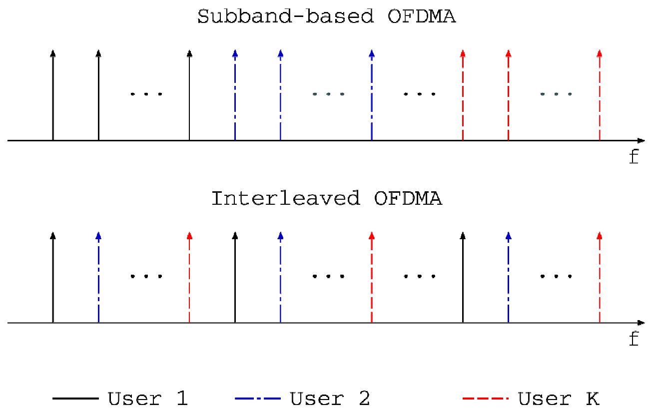


Figure. 1. Illustration of subband-based and interleaved subcarrier assignment schemes [16]

Part II Characterizing The Wireless Ad Hoc Networks by Using The Distance

Distributions

Wireless ad hoc network has been recognized as one of the possible solutions to realize the dream of pervasive computing [1]-[3] especially when nodes are within the *dead zone*, an area where the exiting fixed infrastructures are unavailable, since nodes in the wireless ad hoc network can self-organize and operate without the help of the existing infrastructures. By using the multihop forwarding scheme, nodes in the wireless ad hoc networks exchange messages with other nodes that are not directly connected. Possible examples of the wireless ad hoc networks are tactical military applications, disaster recovery operations, exhibitions or conferences. However, due to the random deployment of the wireless ad hoc networks, the deployed network topologies are also random. As a result, some criterions are commonly used to characterize the random organized network. In this part, we specifically focus on the following three criterions: the optimum transmission range to organize a wireless ad hoc network and the node degree and the connectivity of the organized network. Since the power of the nodes in the wireless ad hoc networks are mainly provided by the batteries, the optimum transmission range (or the critical transmission range) provides us how to power efficiently assign the transmission range either homogeneously or non-homogeneously so that the organized wireless ad hoc network is connected [4]-[7]. The degree of a node is defined as the number of neighbors that are directly connected with [8][9] and is widely used as an index of the connectivity of the organized wireless ad hoc networks [10]. The network connectivity is one of the most important criterions used to characterize the organized wireless ad hoc networks [4]-[7][11]-[13]. This is mainly because for the multihop forwarding scheme in the wireless ad hoc network to be applicable there must exists at least one path between any two nodes so that the messages can be hop-by-hop forwarded to the intended destination nodes. When we look into the three criterions, we find that they are highly related to the distances between the nodes. For example, if the distances between node pairs in the deployed wireless ad hoc networks are short, smaller transmission power is enough for each node to reach its neighbors and, thus, the battery power is conserved. Furthermore, if the transmission range is fixed, shorter distances between nodes result in the higher node degree and the better connectivity of the deployed wireless ad hoc networks. However, due to nodes in the wireless ad hoc networks are in nature randomly and independently distributed into the service area, the distance between any node pair is also random. Thus, it is necessary to study the stochastic property of the distances between nodes. Only few related researches are found in the literatures. In [14], by using two different distributions, uniform and Gaussian, to deploy nodes into the service area, Miller analyzed the distributions of the distance between two nodes in the wireless ad hoc networks and found that similar distance distributions are obtained by using different models to distribute nodes. Thus, he concluded that using a simple model to distribute nodes would be enough for the analysis and simulation of the wireless ad hoc networks. To obtain the joint distribution, Miller presented an alternative approach to find the marginal cdf of the distance between node and a randomly selected reference node (RN) [15]. Then, by employing the independence property, the joint cdf of the distances between nodes and a RN was obtained.

Part III On The Distance Distributions of The Wireless Ad Hoc Networks

Since nodes in wireless ad hoc networks may be randomly and independently spread over the entire service area, the resulting network topologies are diverse and, thus, the separation distance between any selected node pair can be regarded as a random variable. Many characteristics of the wireless ad hoc networks are related to the separation distances between node pairs. One of the most important characteristics for the wireless ad hoc network to be applicable is the connectivity of the organized network. The most common approach to achieve the network connectivity is to maximize the transmission range so that nodes are connected. However, when the power consumption is considered, the transmission range should be optimized to the separation distance to its nearest neighbor. Most of the connectivity related researches [1]-[6] are mainly based on the necessary condition that network is *k*-connected if the minimum node degree of a wireless ad hoc network is *k* [1]. When the wireless ad hoc networks are operated in the ideal environment, the node degree can be easily obtained based on the pathloss model, i. e. the number of nodes within the predefined separation distances. However, in the shadow fading environment, given the separation distances between nodes and a common reference node (CRN), the node degree will dynamically change due to the random fluctuation of the signal strength. Thus, it is necessary to find the joint distance distribution between nodes and a CRN. In this part, we assume that nodes are uniformly and independently deployed within a square service area and the location of each random deployed node *u* is expressed as a vector $\mathbf{u} = (x_u, y_u)$ in $\mathbf{R}^2$. Based on the definition in [8], the *distance function* between nodes *u* and *v* is defined as $r(\mathbf{u}, \mathbf{v}) = ((x_v - x_u)^2 + (y_v - y_u)^2)^{1/2}$ such that (i) $r(\mathbf{u}, \mathbf{v}) \geq 0$, (ii) $r(\mathbf{u}, \mathbf{v}) = 0$ if and only if $\mathbf{u} = \mathbf{v}$, (iii) $r(\mathbf{u}, \mathbf{v}) = r(\mathbf{v}, \mathbf{u})$ and (iv) $r(\mathbf{u}, \mathbf{v}) \leq r(\mathbf{u}, \mathbf{w}) + r(\mathbf{w}, \mathbf{v})$ for any nodes *u*, *v* and *w*. In this case, the distance function is also known as the *Euclidean distance* between nodes *u* and *v* and the square service area is known as the 2-dimensional *Euclidean space*.

The first distance distribution we derived is based on the concept that if the Euclidean distance from a reference node to its *k*-th nearest neighbor is less than the transmission range of the reference node, the minimum degree of the node is *k*. The disadvantage of this distribution is that the prior knowledge of the order of the nearest neighbor of a reference node is required. To this end, we derive the distribution of the Euclidean distance between two random selected nodes without knowing the prior knowledge. Since the obtained results do not poss the independence property, they cannot be applied directly to obtain the joint distribution of the Euclidean distances between nodes and a common reference node. Therefore, we further derive the marginal cdf and pdf of the Euclidean distance between node and a common reference node. Since the obtained marginal cdf and pdf possess the independence property, they can be easily generalized to obtain the joint cdf and pdf. Only few related researches are found in the literatures. The distribution of the *k*-th nearest neighbor is also known as Nearest Neighbor Distribution (NND) in [9][13]. In [14], by using two different distributions, uniform and Gaussian, to distribute the nodes, Miller analyzed the distributions of the Euclidean distance between two nodes in the wireless ad hoc networks and noted that the models used to distribute nodes generate very similar cdfs. Thus, he concluded that using a simple model to distribute nodes would be enough for the analysis and simulation of wireless ad hoc networks. To obtain the joint distribution, Miller presented an alternative approach to find the marginal cdf of the Euclidean distance between two nodes [15]. Then, by employing the independence property, the joint cdf of the Euclidean distances between node pairs that have a common reference node was obtained. In the following analyses, we assume the number of nodes in the network is *N* and ignore the boundary effects.

Part IV Organizing an Optimal Cluster-Based Ad Hoc Network Architecture by the

Modified Quine-McCluskey Algorithm

When wireless nodes are in an area that is not covered by any existing infrastructure, one of the possible solutions to achieve the ubiquitous computing is to enable wireless nodes to operate in the ad hoc mode [1] and selforganize themselves into a cluster-based network architecture. One of the general approaches to build up a cluster-based network architecture is to design an algorithm to organize wireless nodes into set of clusters. Within each cluster, a node is elected as a *clusterhead* (CH) to take responsible for the resource assignments and cluster maintenances. Many related algorithms have been proposed. The *minimum connected dominating set* (MCDS) approach [2] tries to obtain an optimum configuration to be the virtual backbone of the wireless ad hoc networks. However, it is shown to be an NPhard [3] problem. The most feasible alternative is to find an approximated heuristic algorithm to obtain a sub minimum connected dominating set. The general idea among the related literatures is to select CHs based on some attributes of the networks. For example, the node degree, the link delay, the transmission power, the mobility, . . . , etc.. A detail survey of the clustering algorithms can be found in [4].

In viewing the previous works, we find that the minimization of the waste of the precious bandwidth and the limited battery power in exchanging the cluster maintenance overheads has not been well studied. Thus, based on the technique to select the optimum set of prime implicants in the Quine-McCluskey (QM) algorithm [5], we propose a Modified QM (MQM) clustering algorithm to organize the wireless ad hoc network into a cluster-based network architecture that requires the minimum number of cluster maintenance overheads.

Part V A Clustering Algorithm to Produce Power-Efficient Architecture for

(N,B)-Connected Ad Hoc Networks

Wireless ad hoc network is a self-organizing network that can be rapidly deployed and operated without the help of the existing infrastructure. Possible examples of the wireless ad hoc networks can be found in the tactical military applications, disaster recovery operations, exhibitions and conferences. Since there is no existing fixed infrastructure in the wireless ad hoc network, organizing the randomly deployed nodes into a virtual backbone turns out to be an important design issue. One of the general approaches is to organize nodes into groups of clusters. Within each cluster, a node is elected as the local controller of that cluster and is called clusterhead (CH). Major advantages of this approach include frequency spatial reuse, smaller interference and the increase of system capacity.

Many related algorithms [1]-[10] have been proposed in the literatures. The minimum connected dominating set (MCDS) scheme [1] organizes the wireless ad hoc network into an optimum configuration. However, the problem to find the MCDS in a connected graph is shown to be NP-hard [2] and the problem to find the optimal CH set is an NP-complete problem [3]. The general feasible alternative is to design an approximated heuristic algorithm to obtain a sub-optimal MCDS. The Degree-based clustering algorithms [4] are proposed to select CHs based on the degree of the nodes. The ID-based clustering algorithms [5][6] organize the cluster simply based on the node ID. Other approaches that are based on different node attributes can be found in [7]-[9]. Due to the security concerns of the transmitted messages or the limitations of the geography of the service area, some singular nodes must/may be deployed within the service area. For example, some nodes in the networks have only one neighbor and are called boundary nodes. The only neighbors of boundary nodes play an important role in providing connections from boundary nodes to the other nodes. In view of the previous algorithms, we find that the impacts of the boundary nodes on the design of clustering algorithm have not been well studied in the literatures. This part addresses how to organize wireless ad hoc networks with boundary nodes into a power efficient cluster-based network architecture. The power efficiency of a cluster-based network architecture in this part is related to the number of overheads that are required to maintain the organized cluster-based network architecture.

結果和討論

Part I Phase Noise Estimation in OFDM and OFDMA Uplink Communications

We can find the performance of these two CPE estimations by simulation. Consider an OFDMA system with 64 subcarriers in the 5 GHz frequency band. The signal bandwidth is 20 MHz. There are 4 sub-channels in the system, each contains 13 subcarriers. Each active user uses one sub-channel and the configuration and frequency domain structure of each subchannel are identical. We denote N_p the number of pilot subcarriers in a sub-channel and it varies from 1 to 4 in our experiments.

The channel response of each user is generated according the IEEE 802.11a channel model with root-mean-square delay spread equals to 50 ns. The channel coefficients are modeled as independent and complex-valued Gaussian random variables with zero-mean and an exponential power delay profile

$$\mathrm{E}\left\{\left|h_k(l)^2\right|\right\} = \lambda\ ?\exp\{\ l\}, \qquad l = 0,1,\ldots,10.$$

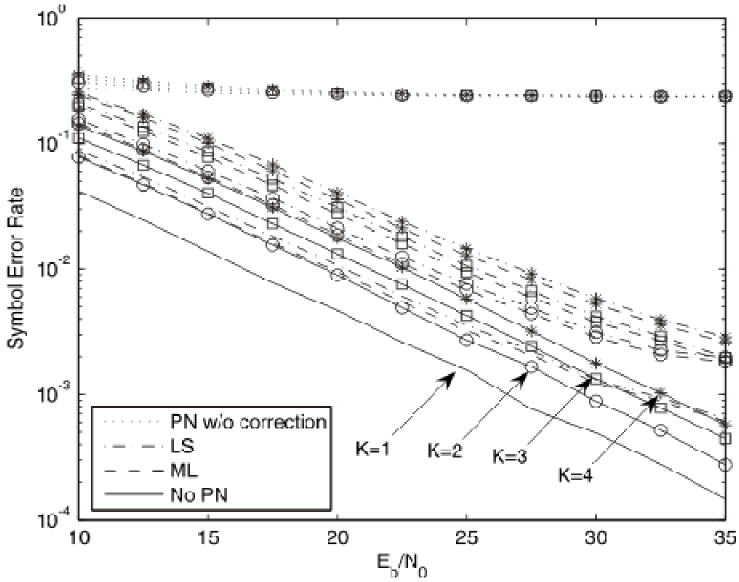
The constant λ is chosen such that the signal power of each user is normalized to unity. The phase noise is generated by the Lorentzian model with β equals to 1 kHz. Two typical subcarrier assignment schemes: sub-band based subcarrier assignment and interleaved subcarrier assignment as illustrated in Fig. 1 are used. Each simulation point is conducted using 3×10^5 frames, each frame consists of 16 OFDM symbols.

Fig. 1 shows the symbol error rate (SER) performance of the two proposed CPE estimators in comparison with both no-phase-noise and no-phase-noise-correction cases with QPSK. Since the number of pilot subcarriers affects the spectrum efficiency and the capacity of an OFDMA system, N_p is set to 1 in the simulation generating these two figures. Fig. 1(a) refers to sub-band based subcarrier assignment while Fig. 1(b) corresponds to interleaved subcarrier assignment.

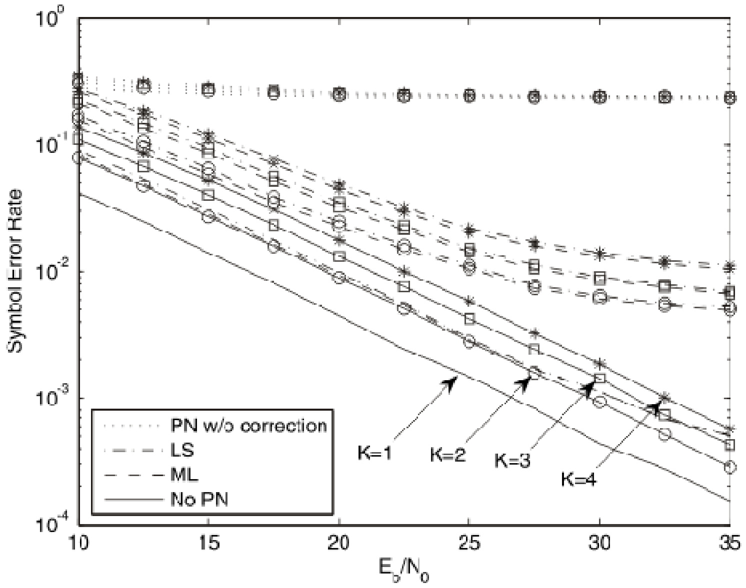
First of all, the maximum likelihood (ML) approaches always have more improvement than least square (LS) ones, which is not surprising because the statistics of ICI term is taken into consideration. We can observe that when the number of active users increases, interleaved subcarrier assignment suffers more from the multiple-access interference because other active user's signals are at nearer subcarriers.

Fig. 2 illustrates how the performance of the proposed schemes changes with phase noise levels. The number of pilot symbols N_p is set to 1. The aim of the proposed schemes is to correct medium to small phase noise, i.e., for phase noise variance bT_s less than 10^{-4}. It shows in Fig. 7 that when phase noise variance is greater than 10^{-5}, the OFDMA system suffers remarkable performance degradation. However, the proposed CPE estimation schemes provide significant performance improvement over no-phase-noise-correction case.

When phase noise variance is less than 10^{-5} for an OFDMA system employing QPSK, we can see the error floor of the proposed schemes. For this phase noise variance range, it is not necessary to take the CPE correction to correct multiple phase noise.

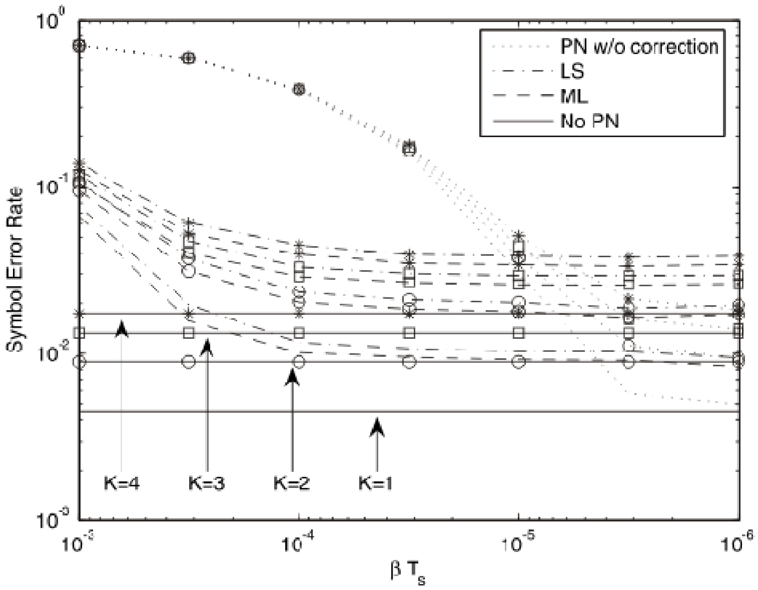


(a) Subband-based

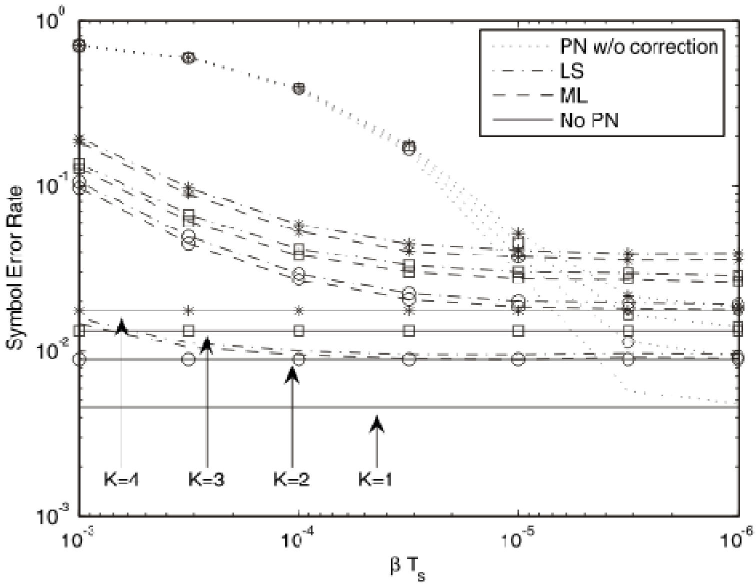


(b) Interleaved

Figure 1. Symbol error rate v.s. SNR with QPSK, K=1 to 4 [16]



(a) Subband-based



(b) Interleaved

Figure 2. Symbol error rate v.s. phase noise variance with QPSK, K=1 to 4 [16]

Part II Characterizing The Wireless Ad Hoc Networks by Using The Distance

Distributions

Table 1 The Optimum Transmission Range for a 1-connected Wireless Ad Hoc Network

	p=0.95		*p*=0.99	
	N=100	*N*=200	*N*=100	*N*=200
r_1^{op}	155.33m	114.75m	171.22m	125.55m

Based on equation, the optimum transmission ranges to construct a 1-connected network r_1^{op} in a 1000m×1000m square-shaped service area with the probability $p=0.95$ and $p=0.99$, $N=100$ and $N=200$ are shown in TABLE 1. The probability of organizing a *k*-connected wireless ad hoc network in the ideal environment obtained in equation is shown in Figure 1. This figure shows that the required transmission range *R* for *N* nodes in the ideal environment to organize a *k*-connected wireless ad hoc network is inverse proportional to *N* and proportional to *k*. For example, from TABLE 1 and Figure 1, the transmission ranges 171.22m and 125.55m are required for a wireless ad hoc network with 100 and 200 nodes to be 1-connected with the probability 0.99. The probability of the wireless ad hoc network organized by *N* nodes in the shadow fading environment is *k*-connected as derived in equation is shown in Figure 2. In this figure, the transmission range *R* is set to 300m which corresponds to a wireless ad hoc network organized by 100 nodes in the ideal environment is 3-connected with the probability greater than 0.9999 as shown in Figure 1. With the same transmission range, Figure 2 shows that as the channel variation is concerned, fewer nodes are required to achieve the same network connectivity and the number of nodes to achieve the required network connectivity is inverse proportional to the channel variation.

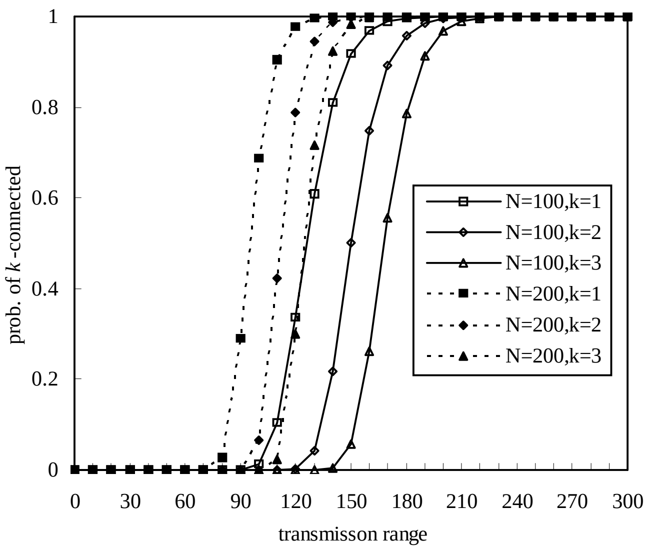


Figure 1 The probability of *k*-connected in the ideal environment.

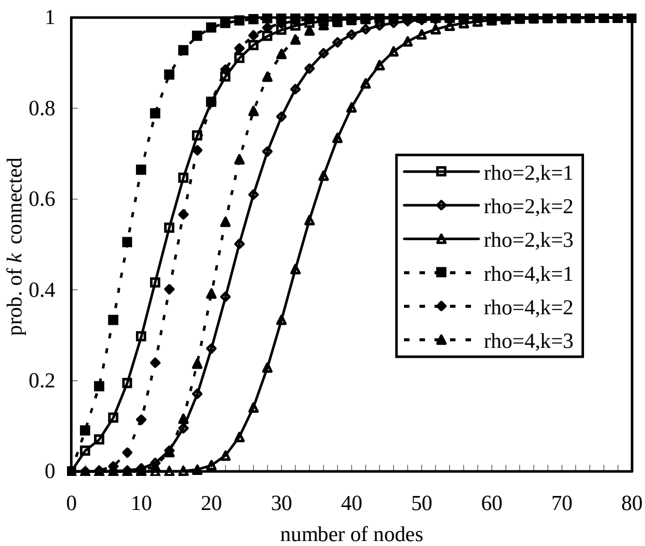


Figure 2 The probability of *k*-connected in the shadow fading environment.

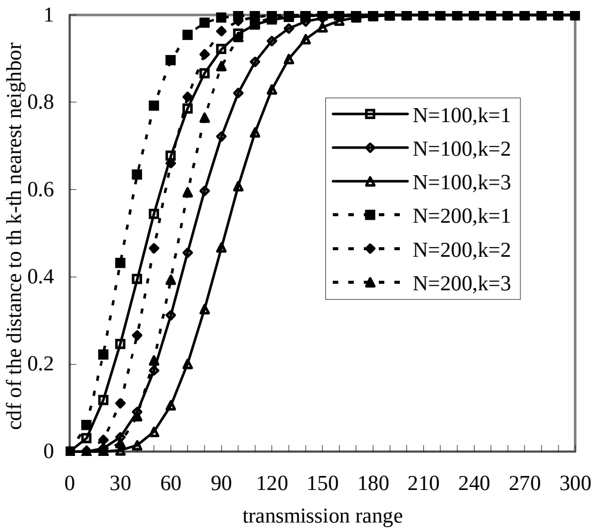


Figure 1 The cdf of the distance to the *k*-th nearest neighbor.

The distribution of the distance to the k-th nearest neighbor

In Figure 1, we show the cdf of the separation distance obtained in equation to the 1st, 2nd and 3rd nearest neighbor for a wireless ad hoc network with 100 and 200 nodes deployed over a 1000m×1000m square-shaped service area. This figure shows that the distance to the *k*-th nearest neighbor is inverse proportional to the number of nodes in the service area. Furthermore, this figure also shows that almost surely that the first nearest neighbor is within the Euclidean distance 120m and 82m for the number of nodes are 100 and 200 respectively.

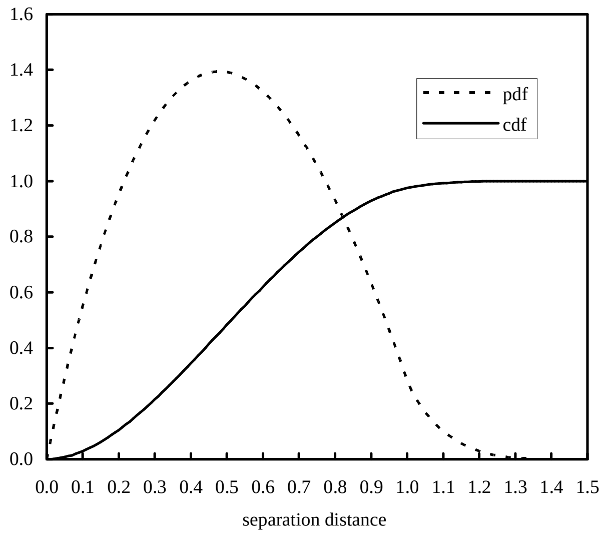


Figure 2 The cdf and pdf of the Euclidean distance between two random selected nodes.

The distribution of the distance between two random selected nodes

The pdf and cdf in equations with different separation distance are shown in Figure 2. By differentiating equation, the most probable normalized separation distance between two random selected nodes is 0.478. This can also be found from Figure 2 that the 0.478 separation distance corresponds to the maximum probability density. Besides, from the cdf curve in Figure 2, we find that if the normalized transmission range is higher than 0.94, the probability for two random selected nodes are connected is more than 0.95.

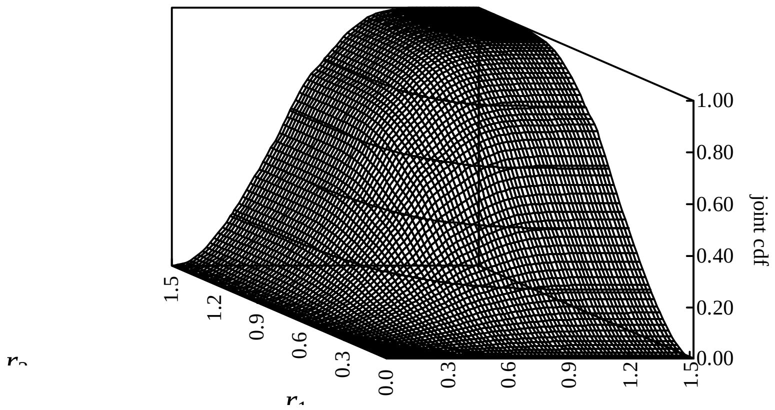


Figure 3 The joint cdf of the distance $F_{shadow}(r_1, r_2)$.

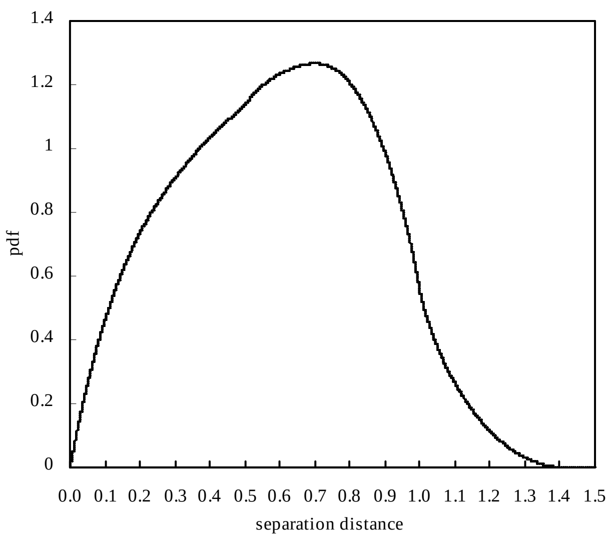


Figure 4 The pdf of the distance between node and a CRN.

The distribution of the distance between node and a CRN

Based on equations, the conditional cdf of the separation distance in equation is obtained. By integrating equation, we can obtain the marginal cdf of the separation distance. Numerical integration of equation has been conducted for the joint cdf of the separation distances r1 and r2. The resulting joint cdf curve is shown in Figure 3.

Following the same procedures, the marginal pdf of the separation distance in equation is shown in Figure 4. In this figure, the most probable normalized separation distance between node and a CRN is about 0.7.

Part IV Organizing an Optimal Cluster-Based Ad Hoc Network Architecture by the

Modified Quine-McCluskey Algorithm

We verify the performance of the proposed MQM algorithm by conducting extensive simulations. In our simulations, we assume the size of the service area is 2000m×2000m, the number of nodes N is 300 and the transmission range for each node is 300m. We run the simulation 10,000 times and average the collected data. In each simulation, we first randomly deploy the non-boundary nodes into a connected sub-network. Then, for each boundary node, a node in the connected subnetwork is randomly selected to be its only neighbor (i. e., the critical node). For the performance comparisons, the MQM and the Degree-based [6][7] clustering algorithms are used to cluster each of the generated network topology. As stated before, our objective is to design a clustering algorithm that can organize a cluster-based network architecture in which the required number of cluster maintenance overheads is minimized. In derived equation, the number of cluster maintenance overheads mainly depends on the number of generated clusters and the variance of the number of cluster members. The simulation results for the number of generated clusters and the variance of the number of cluster members are shown in Fig. 1 and Fig. 2 respectively. Since the original QM algorithm is designed to obtain the minimum set of PIs, the proposed MQM algorithm generates the minimum number of clusters as shown in Fig. 1. Furthermore, due to unchecked node is selected as a CH only if it is the critical node with the highest logical degree among its one-hop neighbors or it is the node with the highest logical degree among its two-hop neighbors, the number of clusters that are generated by the boundary node and the difference of the number of cluster members between clusters are minimized. Therefore, as shown in Fig. 2, the variance of the number of cluster members is minimized. Consequently, the number of cluster maintenance overheads as shown in Fig. 3 is minimized and the generated cluster-based network architecture is optimal.

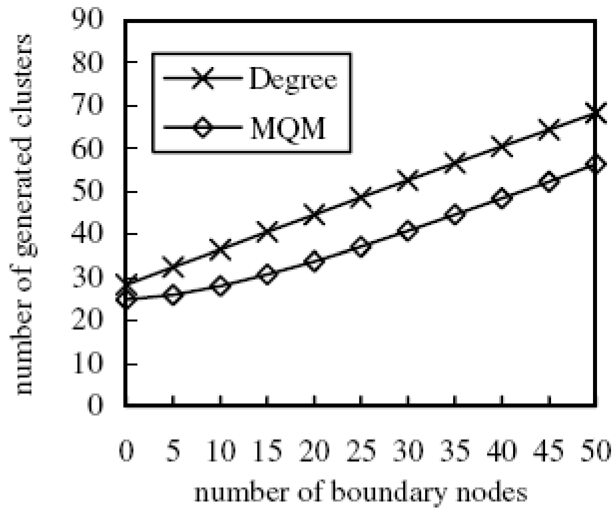


Figure 1. The number of generated clusters

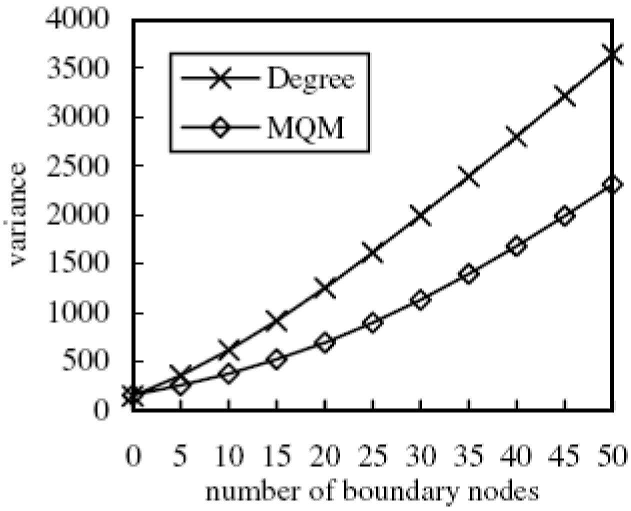


Figure 2. The variance of the number of cluster members

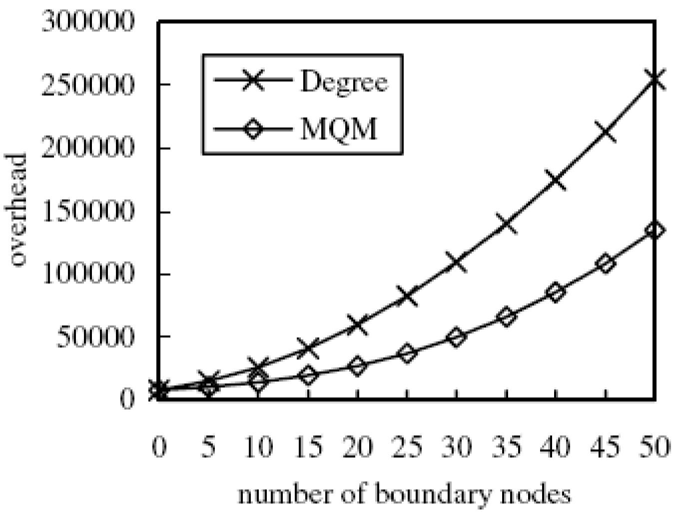


Figure 3. The number of cluster maintenance overheads

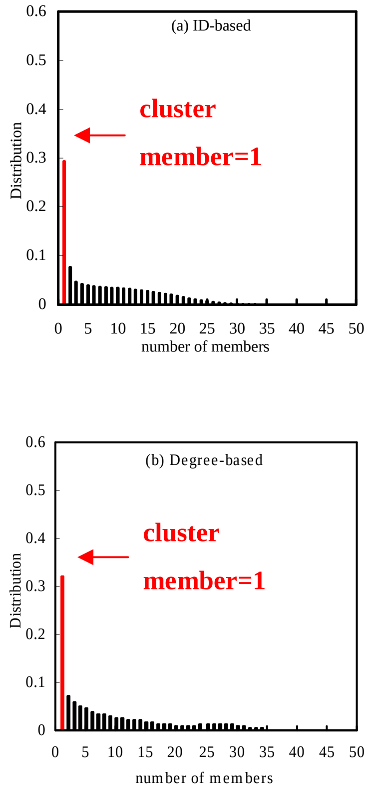
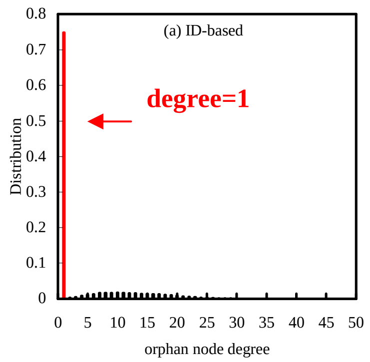


Figure 1 Distributions of the number of cluster members for clusters generated by the (a) ID-based and (b) Degree-based clustering algorithms.



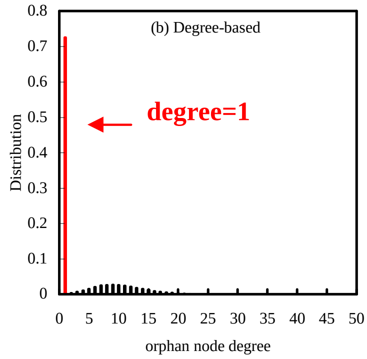


Figure 2 Degree distributions of the orphan nodes generated by the (a) ID-based and (b) Degree-based clustering algorithms.

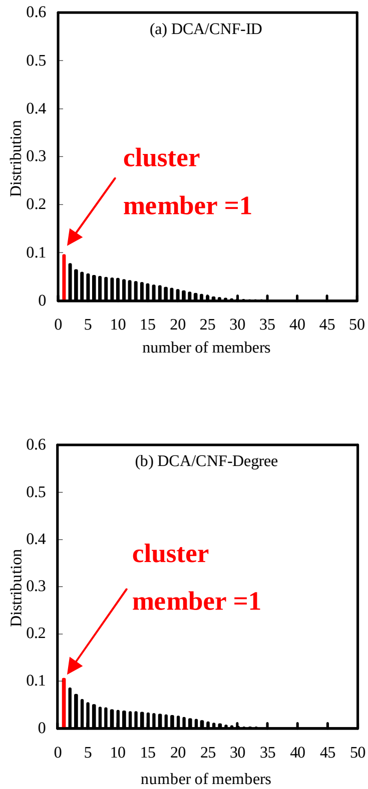
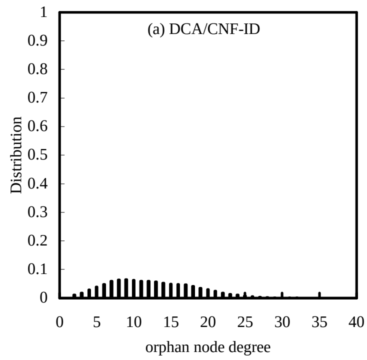


Figure 3 Distributions of the number of cluster members for the (a) DCA/CNF-ID and (b) DCA/CNF-Degree clustering algorithms.

We evaluate the performance of the DCA/CNF-ID and DCA/CNF-Degree approaches by conducting 10,000 simulations. We compare the simulation results with the ID-based and Degree-based algorithms. The service area is a 2000m×2000m square area. In each simulation, a (300,10)-connected wireless ad hoc network topology is randomly generated. Then, the ID-based, Degree-based, DCA/CNF-ID and DCA/CNF-Degree algorithms are used to organize the randomly generated network topology into a cluster-based network architecture. Figure 3 shows the distributions of the number of the cluster members for the DCA/CNF-ID and DCA/CNF-Degree approaches respectively. Comparing with the results as shown in Figure 1, we can easily find that the number of orphan clusters generated by the proposed DCA/CNF-ID and DCA/CNF-Degree approaches is greatly reduced.



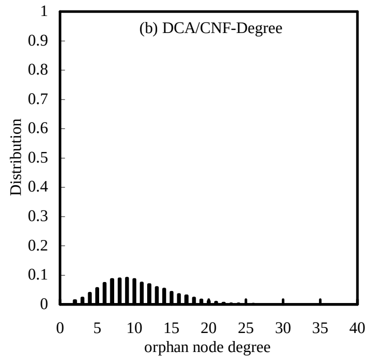


Figure 4 Degree distributions of orphan node generated by the (a) DCA/CNF-ID and (b) DCA/CNF-Degree clustering algorithms.

In Figure 5, we show the distributions of the degree of the orphan node generated by the DCA/CNF-ID and DCA/CNF-Degree approaches respectively. Comparing with the results as shown in Figure 2, no orphan nodes are boundary nodes!! In addition, we can also find that, with higher probability, the degree of the orphan nodes generated by the DCA/CNF-ID and DCA/CNF-Degree approaches is higher than that generated by the ID-based and Degree-based clustering algorithms. This is a good news since a higher degree of an orphan node implies that more chances for the orphan node to change into non orphan node either by joining a cluster organized by its one-hop neighbor or inviting its one-hop neighbors to join the cluster that it organizes when the cluster architecture is re-organized.

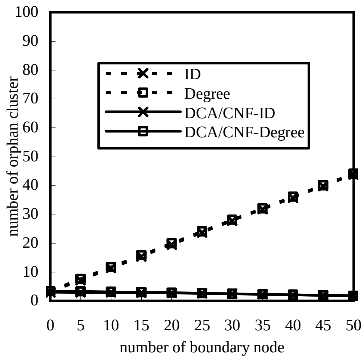


Figure 5 The number of generated orphan clusters.

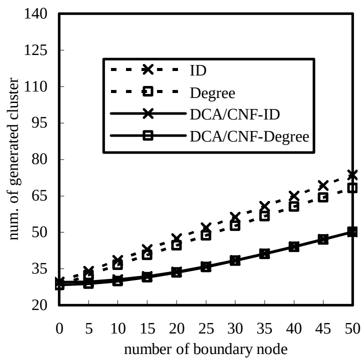


Figure 6 The number of generated clusters.

The number of generated orphan clusters and the number of generated clusters are shown in Figure 5 and Figure 6 respectively. As stated in proposition , the number of generated orphan clusters in Figure 5 is reduced by assigning critical node the highest weight in the proposed approaches. In Figure 6, it is obviously that the number of generated clusters by the DCA/CNF-ID and DCA/CNF-Degree is reduced due to the reduction of the number of generated orphan clusters as stated in proposition.

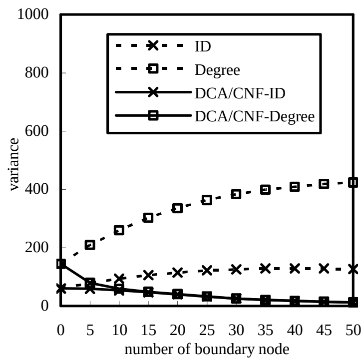


Figure 7 The variance of the number of cluster members.

Figure 7 shows the variance of the number of cluster members. As we mentioned before, due to the generated clusters are dominated by orphan clusters, the variance of the numbers of cluster members of the ID-based and Degree-based cluster algorithms are very high. On the contrary, due to the reduction of the number of generated orphan clusters, the proposed approaches reduce the variance of the number of cluster members. This figure also shows the Degree-based clustering algorithm is with the highest variance of the number of cluster members. This is because that CHs located in the dense area will have a larger number of cluster members than that located in the sparse area.

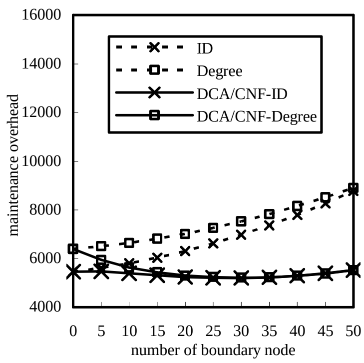


Figure 8 The number of cluster maintenance overheads.

Figure shows the number of cluster maintenance overhead. Since the variance of the cluster members of the Degree-based clustering algorithm is much higher than the other three clustering algorithms as shown in Figure 7, according to equation and Figure 6, it has the maximum number of cluster maintenance overheads. By reducing the number of generated clusters and the variance of the cluster members, the number of cluster maintenance overheads for the proposed DCA/CNF based approaches is reduced. As a consequence, the limited battery power is conserved. Finally, from Figure to Figure , we also observe that there is only little difference between results obtained by DCA/CNF-ID and DCA/CNF-Degree approaches. Based on this observation, we suggest that if the degree information of the neighboring nodes is not available or the node degree changes very frequently due to the mobility of the nodes or the dynamics of the channel quality, the DCA/CNF-ID approach is a good approach to organize the wireless ad hoc networks. However, if the degree information for neighboring nodes is available and the disadvantage of the biased CH election criterion to the lowest ID node is concerned, the DCA/CNF-Degree approach is a better approach to organize the wireless ad hoc networks.

成果與自評

Part I Phase Noise Estimation in OFDM and OFDMA Uplink Communications

In this part, several phase noise models and the corresponding effects in OFDM and OFDMA systems are introduced. Among them, for the oscillator phase noise, we discussed the estimation of Wiener phase noise and stationary phase noise. Finally two multiuser phase noise estimation algorithms to mitigate the effects of multiple phase noise in uplink OFDMA systems are proposed. The LS approach provides acceptable performance with low complexity while the ML approach considers the second order statistics of the ICI to enhance the performance. The proposed schemes aim to compensate for CPE, the major effect of phase noise for medium to low phase noise levels where phase noise correction is applicable. Moreover, these two multiuser phase noise correction schemes are stable within a wide range of phase noise levels and applicable to any subcarrier assignment scheme, which shows its potential in practical applications.

Part II Characterizing The Wireless Ad Hoc Networks by Using The Distance

Distributions

To achieve pervasive computing in the absence of the existing infrastructure, nodes in the service area organize themselves into a wireless ad hoc network. Due to the random locations of the nodes, the distances between nodes are random. In this part, two distance distributions are presented and used as the foundations to characterize the organized wireless ad hoc networks. Given the prior knowledge of the order of the nearest neighbors, the nearest neighbor probability distribution in the theorem provides us how to use the optimum transmitting range to connect to the *k*-th nearest neighbor or, equivalently, how to power-efficiently deploy a *k*-connected wireless ad hoc network. Based on the marginal and the joint distribution of the distances between nodes and a RN in the theorem, we analytically show that the exact node degree of the wireless ad hoc network in the shadow fading environment is a binomial distribution. With the exact distribution of node degree, we further obtain the probability of the minimum node degree of the wireless ad hoc network that is the necessary condition of the network connectivity. Our results also show that the connectivity of the organized wireless ad hoc network in the shadow fading environment is improved due to the random fluctuation of signal strength.

Part III On The Distance Distributions of The Wireless Ad Hoc Networks

This part investigates the probability distributions of the random separation distances between node pairs in the wireless ad hoc networks. By using the concept of the Euclidean distance in the 2-dimensional Euclidean space, the first probability distribution, the distribution of the Euclidean distance to the *k*-th nearest neighbor, is obtained. Using the technique of function of random variables, we obtain the probability distribution of the Euclidean distance between two random selected wireless nodes. Then, through the computation of the union area on the node coverage area and a unit square, we derived the marginal cdf and pdf of a wireless node pair. Since the Euclidean distances between wireless node pairs with the common reference wireless node are mutually independent, we can easily extend the marginal cdf and pdf to obtain the joint cdf and pdf of the Euclidean distances between wireless node pairs in the wireless ad hoc network with *N* wireless nodes that are randomly and uniformly distributed over a unit square.

Part IV Organizing an Optimal Cluster-Based Ad Hoc Network Architecture by the

Modified Quine-McCluskey Algorithm

To reduce the waste of precious bandwidth and the limited battery power in exchanging the cluster maintenance overheads, we propose a distributed Modified Quine-McCluskey (MQM) algorithm to organize the wireless ad hoc network into an optimal cluster-based network architecture that requires the minimum number of cluster maintenance overheads. Simulation results show that by minimizing the number of generated clusters and the variance of cluster members, the organized cluster-based network architecture requires the minimum number of cluster maintenance overheads. Thus, the optimal cluster-based network architecture is organized.

Part V A Clustering Algorithm to Produce Power-Efficient Architecture for (N,B)-Connected Ad Hoc Networks

Through analyses, we find that reduction of the number of cluster maintenance overheads for a (*N*,*B*)-connected cluster-based wireless ad hoc network can be achieved by reducing the number of generated cluster and the variance of the number of the cluster members. By analyzing the cluster architectures generated by the ID-based and Degree-based clustering algorithms, we find that the number of generated cluster and the variance of the number cluster members can be reduced by reducing the number of orphan clusters generated by boundary nodes. Simulation results show that by assigning critical nodes the highest weights (or priorities) to be selected as CHs, the number of generated clusters and the variance of the number of cluster members for the cluster-based network architecture generated by the proposed DCA/CNF based approaches are reduced. As a consequence, the number of cluster maintenance overheads is reduced and the organized network architecture is power efficient.

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Distributions

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出席國際學術會議心得報告

計畫編號	NSC 95-2219-E-002-024-
計畫名稱	民生網路之前瞻研究-子計畫五:多標準共存之可調無線介接與正交分頻(1/2)
出國人員姓名 服務機關及職稱	陳光禎 台大電信所 教授
會議時間地點	2006.09.11 – 2006.09.14 芬蘭−赫爾辛基
會議名稱	The 17th Annual IEEE-International Symposium on Personal Indoor and Mobile Radio (PIMRC 2006)
發表論文題目	Fair Adaptive Radio Resource Allocation of Mobile OFDMA

一、參加會議經過

本人此次榮幸參加於芬蘭赫爾辛基舉行之 The 17th Annual IEEE-International Symposium on Personal Indoor and Mobile Radio (PIMRC 2006) 。PIMRC 自 1990 年起迄今每年舉辦一次，今年為第 17 屆。此次 PIMRC 的議題為「電信的多樣性」(Diversity in Telecommunications)，是由芬蘭的三所大學所主辦。會期自九月十一日至九月十四日，為期共四天。此會收錄超過 900 篇的論文，本人也發表了 1 篇論文，題目為 Fair Adaptive Radio Resource Allocation of Mobile OFDMA。此會另有口頭報告及海報展示，是相當成功且大型的國際研討會。

有 7 個 panel sessions:

1. Impregnating Wireless Communication into People’s Life
2. Ultra (UWB)
3. Mobile IP and Mobile TV: Trends and Strategies
4. Issues in Dynamic Spectrum Management
5. Trends and Challenges
6. Cooperative Techniques for Future Wireless Communication Systems
7. Applications of Wireless Sensor Networks

有 3 個 special sessions:

1. Global Research Activities on Future Broadband Wireless Systems

2. Flexible Spectrum Usage

3. Future Wireless Technologies

有 9 個 technical sessions(A-I):

A. Business, Services and Applications

B. 3G and WLAM Evolution

C. Ad-hoc and Sensor Networks

D. Network Management

E. Cellular Network Techniques

F. Transceiver Techniques

G. MIMO Systems and Techniques

H. Modulation and Coding

I. Physical Layer and Channel Modelling

二、與會心得

參與本次會議，主要是在於發表我們的研究心得，題目是「Fair Adaptive Radio Resource Allocation of Mobile OFDMA」，此篇論文被安排在 Track E: Cellular Network Techniques 的 Wireless Networks I 場次最後一篇，會議是由 VTT Electronics 的 Marcos Katz 主持。除了發表我們的研究成果，有機會和出席成員討論、吸取他們的意見，綜合如下：

1. 由會議的名稱與議程內容來看，本會議著重在一些最熱門的無限通訊技術之探討，如 Cognitive radio network, Ad hoc network, UWB, MIMO-OFDM，且涵蓋電信多項領域，切合會議主題:電信的多樣性。而來自世界各地學術界、產業界無線通訊領域的專家學者，互相交流討論意見，對於通訊領域專業知識的提昇，以及未來研究獲益良多。

2.在這次會議中，來自台灣的論文約有四五篇，分別來自台大（兩篇）、清大與成大（一篇）。雖然數量上並非大宗，但也顯示台灣在熱門的無線通訊領域中佔有一席之地。

FAIR ADAPTIVE RADIO RESOURCE ALLOCATION OF MOBILE OFDMA

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Abstract - Orthogonal Frequency Division Multiple Access (OFDMA) is a promising technique which can provide high capacity in future communication systems. The total capacity of OFDMA can be maximized by dynamically allocating sub-carriers among users according to channel condition. However, it is quite challenging to properly allocate sub-carriers in mobile channels due to the time varying property. Existing approach designed for static users assigned the sub-carriers with the best SNR to increase the total capacity but to lose fairness. Fairness can be restored by using max-min criterion or constraint limiting the ratios of user data rates to maintain some balance among users. But when users are mobile, the SNR considered should be replaced by the carrier to interference ratio (CINR) because of the presented inter-carrier interference (ICI) due to Doppler Spread. In this paper we successfully incorporate the ICI into our radio resource allocation algorithm to simultaneously optimize the total capacity and fairness for mobile users. The fairness and priority of user traffic are jointly considered in our adaptive algorithm. The algorithm is demonstrated outperforms the existing algorithm designed for static users, and very robust in realistic operation.

I. INTRODUCTION

Wireless broadband communications become an extremely attractive research to transport multimedia traffic. To provide such high bandwidth physical transmission, one of the key design issues is to decide an appropriate multiple access scheme. Orthogonal frequency division multiplexing (OFDM) is widely considered for high-spectral efficient wireless communications, and has been adopted in wireless LANs, UWB, WiMAX, etc. To further utilize cross-layer radio resource, orthogonal frequency division multiple access (OFDMA) is widely considered in wireless broadband communications.

OFDMA is a multiple access technique inherited the ability of OFDM to combat inter-symbol interference (ISI), which can provide higher spectral efficiency by appropriate distributing radio resource [1]. Existing research include allocation of radio resource among static users for OFDMA systems [2] [3] [4] [5], and some of them considering fairness [4] [5]. Mobility has rarely been considered in literatures. In this paper we first incorporate the Doppler Spread into system optimization, and propose an algorithm to distribute the sub-carriers among mobile users to maximize total capacity and maintain fairness. Although the oscillator deviation, channel/environment variations and user's velocity all result in Doppler Spread we use generalized velocity to represent the combined effect of them.

The priority of each user was included as a part of fairness consideration which can be adaptively adjusted in our algorithm. We develop theoretical analysis and simulations to illustrate the advantages of the proposed algorithm over the static schemes without considering mobility. At last, we demonstrate our approach is quite robust to the frequency estimation which has been included for estimating Doppler Spread.

The organization of this paper is as follows. We first give the system model and formulate the radio resource allocation optimization for mobile OFDMA system in Section II. Some considerations were discussed in the same section. In section III, we give an experimental study to demonstrate the advantages of our algorithm over the existing static approach. In Section IV, we consider a more realistic case including Doppler Spread Estimator and demonstrate the robustness of our algorithm against the frequency estimating error. Finally we give some discussions and conclusion in Section V.

II. SYSTEM MODEL

A. Analysis of ICI

Inter-carrier interference (ICI) due to Doppler Spread results in the loss of orthogonality among sub-carriers. To include the mobility in our optimization, the ICI needed to be analytically analyzed [6].

Figure 1 depicts a discrete-time baseband equivalent model of OFDM system. b_s represent the source bits, symbol generator outputs symbols a_n. The serial to parallel converter transfers blocks of symbols to the OFDM modulator, which use an N-point IFFT to modulate them onto the sub-channels. A guard interval of length G is then be added to give a transmitted sequence corresponding to samples at $t = iT_s$

$$X_i^g = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} a_n \exp\left(j \frac{2\pi ni}{N} \right) \qquad 0 \le \mathrm{i} \le N + G - 1 \tag{1}$$

where i and n are time and sub-carrier index. X_i^g is a sequence with guard interval.

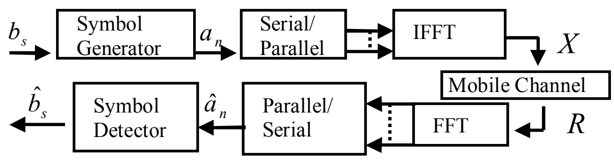

Figure 1: Communication System Using OFDM.

As [6], the received sequence from the multi-path channel has the form

$$R_i^g = \sum_{m=0}^{M-1} H_{m,i} X_{i-m}^g \qquad 0 \le \mathrm{i} \le N + G - 1 \tag{2}$$

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where $H_{m,j}$ is the channel impulse response at path *m* and instant *i*. After removing the guard interval and demodulating by FFT, we can use the result of [7] [8] to separate the desired part and the ICI part of the received sequence in frequency domain as

$$\hat{a}_n = a_n S_0 + \sum_{l=0, l\neq n}^{N-1} a_l S_{l-n} + w_n \tag{3}$$

where

$$S_{l-n} = \frac{\sin[\pi(l-n+\varepsilon)]}{N\sin\left[\frac{\pi}{N}(l-n+\varepsilon)\right]}\exp\left[j\pi\left(1-\frac{1}{N}\right)(l-n+\varepsilon)\right] \tag{4}$$

is the ICI effect of sub-carrier *n* from the sub-carrier *l* in the same OFDM symbol. $\varepsilon = f_d / \Delta f$ is the normalized frequency offset. $f_d = v/c * f_c$ is the Doppler Frequency Shift due to user generalized velocity *v* and center frequency f_c, Δf is the sub-carrier space.

B. Optimization Formulation

We can formulate our optimization of radio resource allocation based on above mathematical form of ICI effect in mobile OFDM system. Figure 2 is the proposed OFDMA system. The Doppler Spread due to each user's generalized velocity was estimated by the frequency estimator, which will be further discussed in section IV. We assume all other channel information is known at the transmitter in this paper and introduce the proposed sub-carriers allocation algorithm.

There are *K* users in the system and the *k*th user has data rate equal to R_k bits per second. The serial data from the *K* users are fed into one sub-carrier allocation block which allocates sub-carriers to different users. We sssume the OFDMA system occupies total signal bandwidth *B* with *N* data sub-carriers and each data sub-carriers bandwidth is *B/N*. Maximum allowable total power for all users is P_{total}. Each of the *K* users has instantaneous generalized velocity v_k corresponding to Doppler Frequency Shift f_{dk} and thus normalized frequency offset ε_k.

Our objective is to optimize the sub-carriers allocation in order to maximize total capacity and maintain fairness among users under the total power constraint. We introduce the adaptation rule to be the fairness consideration. The benefit of introducing this rule is we can explicitly control the user data rates subject to system requirement.

Mathematically, the optimization considered in this paper is formulated as Equation (5). Where $P_{k,n}$ is the power assigned to user *k*'s sub-carrier *n*, $h_{k,n}$ is channel gain on user *k*'s sub-carrier *n*. The second constraint using the indicator $\omega_{k,n}$ to show that each sub-carrier can only be assigned to one user. N_0 is the power of additive white Gaussian noise (AWGN).

$$\max_{P_{k,n},\omega_{k,n}} \sum_{k=1}^{K}\sum_{n=0}^{N-1} \omega_{k,n} \log_2\left(1+\frac{P_{k,n}|S_k(0)|^2 h_{k,n}^2}{P_{k,n}h_{k,n}^2 \sum_{l=0, l\neq n}^{N-1}|S_k(l-n)|^2 + N_0 \frac{B}{N}}\right) \tag{5}$$

Subject to

$$(i) \sum_{k=1}^{K}\sum_{n=1}^{N} P_{k,n} \le P_{total}\ ,\ P_{k,n} \ge 0 \text{ for all } k,n$$

$$(ii) \sum_{k=1}^{K} \omega_{k,n} = 1 \text{ for all } n, \omega_{k,n} = \{0,1\} \text{ for all } k,n$$

$$(iii) \frac{R_k}{T} = \frac{f(p_k, v_k)}{\sum_{k=1}^{K} f(p_k, v_k)}$$

The user data rate R_k is defined as

$$R_k = \sum_{n=0}^{N-1} \omega_{k,n} \log_2\left(1+\frac{P_{k,n}|S_k(0)|^2 h_{k,n}^2}{P_{k,n}h_{k,n}^2 \sum_{l=0, l\neq n}^{N-1}|S_k(l-n)|^2 + N_0 \frac{B}{N}}\right) \tag{6}$$

and *T* is the optimized total capacity. $f(p_k\ v_k)$ is a function of the user priority weighting p_k and the generalized user velocity v_k of the *k*th user. Which can be arbitrary selected for different relationship from user data rates to user priorities and user generalized velocities. The system designer may consider the fairness is both providing higher data rates for high priority users and giving lower data rates to high generalized velocity users when all users have the same priorities, or just granting the sub-carriers according to user priorities without considering generalized velocities. The definition of fairness can be controlled by the system designer.

The constraint *(iii)* is the adaptation rule we proposed for considering fairness which denotes the user data rates can be adaptively adjusted. We uniformly distribute $P_{k,n}$ among all sub-carriers in this paper because the total data throughout is close to total capacity even with flat transmit power spectral density [1] [12].

Equation (5) is the optimization of the adaptive fair radio resource allocation under mobile channels. This equation can be readily solved by standard numerical package such as AMPL [9]. Some differences between mobile and static environments will be discussed later.

C. Alternative Criterion and Constraint

In Equation (5), the criterion is to optimize the total capacity, but there is another criterion being used in static algorithm. Max-min criterion has been used to maximize the minimum capacity of all users and maintain some fairness among users. However, max-min approach is inappropriate for mobile channels, because the power of ICI is much greater than the additive noise [8]. If we maximize the minimum capacity, all users will be given almost equal data rates. It is inappropriate when different users have different priorities. It should be noted, the adaptation rule is essential, or the user with the least velocity gains all sub-carriers. Please note that, all users needed to be included in this constraint to avoid a user getting no sub-carrier allocation.

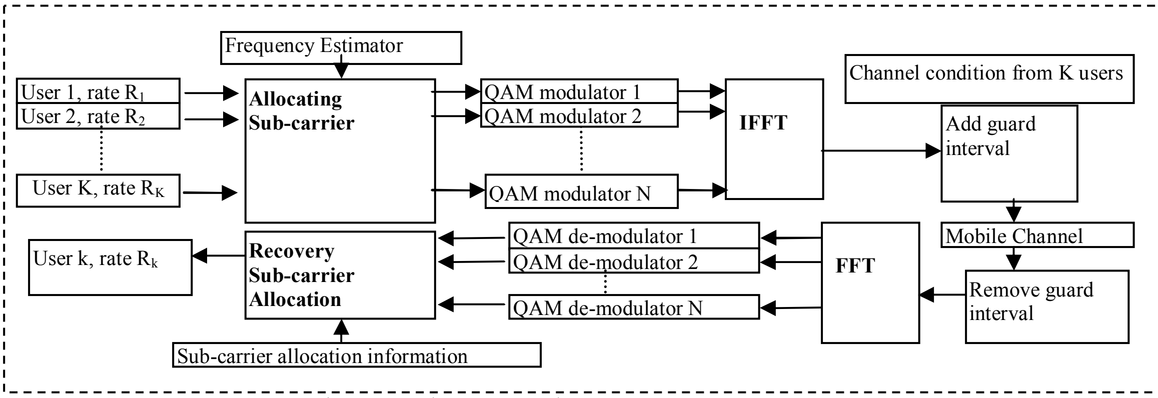

Figure 2: The Proposed OFDMA System

III. Experimental Study

In this section we consider an OFDMA system with 64 sub-carriers and 4 users (A,B,C,D). We select $f(p_k\ v_k) = p_k/v_k^z$ and and $z = 1$ in this and next section as an example. The generalized velocity of each user is assumed to be known at the transmitter as Table 1 in this ideal case. We consider a more realistic case in the next section.

Table 1: Generalized User Velocity in the Experimental Study

User	A	B	C	D
Generalized Velocity (Km/Hr)	30	60	70	90

We list the six cases we considered in this section. The simulation results were demonstrated in Table 2 and Table 3. 'L' and 'H' after the generalized user velocity denote user's priority. 'C_{total}' denotes the total capacity.

Case I : The proposed algorithm but without the adaptation rule (without considering fairness).
Case II : The proposed algorithm but the adaptation rule only include two users
Case III : Max-Min Criterion
Case IV : The proposed algorithm with all users have the same priorities ($p_A=p_B= p_C=p_D=1$)
Case V : The proposed algorithm with user C has high Priority. ($p_c = 3$ and $p_A=p_B=p_D=1$)
Case VI: The proposed algorithm with user C has higher priority ($p_c = 5$ and $p_A=p_B=p_D=1$)

Case I represents just maximizing the total capacity of all users, not taking account of user priorities and fairness among users. From the results we can see the user with the least velocity takes away all the sub-carriers. Giving the user with the least generalized velocity more sub-carriers in effect increasing total capacity, and the total capacity and fairness become trade-ff in mobile channels. Case II denotes we just include the maximum generalized velocity user and minimum generalized velocity user in the adaptation rule, and maximizing the total capacity. We can see only the user had been included in the adaptation rule get sub-carriers.

Table 2:
Demonstrating the Necessity of Adaptation Rule and the Deficiency of Max-Min Criterion for Mobile Channels

	User A	User B	User C	User D	C_{total}
Case I	341.8	0	0	0	341.8
Case II	218.8(L)	0(L)	0(L)	72.9(L)	291.7
Case III	64.1(L)	63.3(L)	62(L)	60.3(L)	249.7

Case III changes the criterion to maximize the minimum capacity of all users. It seems some fairness among users was achieved, but user priorities have not been considered. It means even if the user C has high priority and the other users are low priority users, max-min criterion still gives the same result as case III which grants all users almost equal data rates and can not be adaptively adjusted.

Case IV is our proposed algorithm, maximizing total capacity with priority and fairness consideration. To demonstrate our algorithm is adaptive, case V and VI consider the cases when user C is high priority user and the other users are low priority users. By choosing $p_A=p_B=p_D=1$ and $p_C>1$, we can see the ratios of data rates among users can be adaptively adjusted in our algorithm.

Table 3: Simulation Results to Demonstrate the Adaptation for User Priorities of the Proposed Algorithm

	User A	User B	User C	User D	C_{total}
Case IV	122.7(L)	56.3(L)	51.7(L)	41.2(L)	271.9
Case V	83.6(L)	41.8(L)	108(H)	28(L)	261.4
Case VI	64.2(L)	32(L)	137(H)	21(L)	254.2

We then compare the proposed radio resource allocation algorithm to the static approach [4], which does not consider the mobility.

Table 4: Comparing the Adaptation of the Proposed Algorithm and the Static Algorithm

User		A	B	C	D
Velocity (km/hr)		30(L)	89(H)	90(H)	91(H)
Data Rate	Proposed	43	61	60	57
	Static	69	55	54	53
Velocity (km/hr)		30(L)	89(H)	90(L)	91(L)
Data Rate	Proposed	80	105	25	25
	Static	112	92	22	22

The results of comparison have been demonstrated in Table 4. Considering the first case, User B,C,D have high priorities, the system should give them higher data rates even they have higher generalized velocities. The proposed algorithm satisfies this requirement, but the static algorithm can not achieve that. In the second case we can see the same deficiency of the static algorithm. Although user B has high priority, the static algorithm still gives him lower data rate.

We have numerical demonstrated the differences between static and mobile algorithms. In the next section, we consider a more realistic case and discuss the frequency estimator in Figure 2.

IV. ROBUST TO PHYSICAL TRANSMISSION

A. Frequency Estimator

We assumed the generalized velocity of each user is known at the transmitter in above ideal case. But in fact we need an estimator to estimate the Doppler Spread due to generalized user velocities. The frequency estimator in Figure 2 was used to estimate Doppler Frequency Shift.

B. Block Diagram

Earlier research already demonstrated effective estimation of Doppler Frequency Shift, which is shown in Figure 3 [10] [11]. Consequently, it is enough to consider random behaviors of frequency estimation in studying the proposed algorithm.

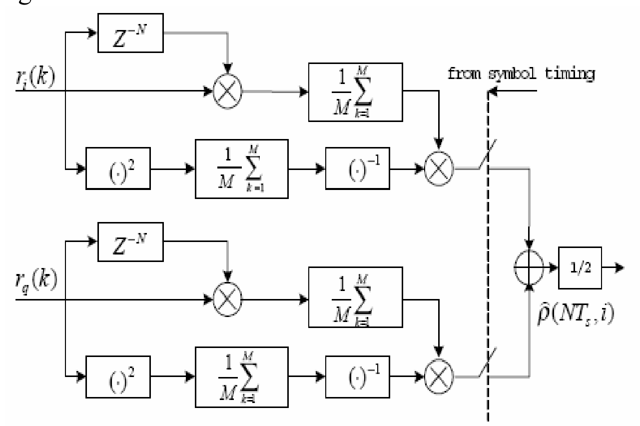

Figure 3: Block Diagram of Frequency Estimator

C. Evaluating the Effect of Estimating Error

The estimating error from frequency estimation introduces several effects. First, the fairness among users considered in the adaptation rule was assumed to closely relate to the user generalized velocities and thus the estimated Doppler Frequency Shift. The estimating error destroys fairness. Furthermore, the Doppler Frequency Shift has been used to allocate sub-carriers; the estimating error may influence the total capacity. For simulating those effects, we consider an OFDMA system with four users and 64 sub-carriers at f_c = 3.2 GHz. All users are assumed to have the same priority but different generalized velocities. The error of estimation is normalized to the theoretical Doppler Frequency Shift f_d.

Table 5 list the configuration we used in simulation to evaluate the effect of estimating error. The first line is user generalized velocity v_k (Unknown to Transmitter); the second line is the theoretical Doppler Frequency Shift f_{dk} under those generalized velocities. We first choose the estimating error equal to $(0.1)f_{dk}$ to give a detail analysis of the effect of estimation, and then we further discuss the conditions for larger estimating error.

Table 5: Configuration to Evaluate Estimating Error

User	A	B	C	D
Velocity (v_k :Km/Hr) (Unknown to Tx)	30	60	70	90
Ideal Doppler Frequency Shift under above Generalized User Velocity ($f_{dk} = v_k/c{*}f_c$ Hz)	89	178	207	267
Estimating Error $(0.1)f_{dk}$	8.9	17.8	20.7	26.7

Under the scale of estimating error, we list all types of frequency estimating error and the simulation result in Table 6. "+" after user k denotes the estimator overestimate the f_{dk} by $(0.1)f_{dk}$ and "-" after user k denotes the estimator underestimate the f_{dk} by $(0.1)f_{dk}$. 'C_{total}' denotes total capacity and 'Ideal' denote the ideal case considering the theoretical Doppler Frequency Shift.

Table 6: Simulation Results to Evaluate the Frequency Estimating Error under Sixteen Error Types

Error type	User A Data Rate	User B Data Rate	User C Data Rate	User D Data Rate	C_{total}
Ideal	122.7	56.3	51.7	41.2	272
A+B+C+D+	117.3	60.3	51.7	41.2	271
A+B+C+D-	117.3	56.3	51.7	44.3	270
A+B+C- D+	111.9	56.2	59.1	41.1	269
A+B+C- D-	111.9	56.2	55.4	44.3	268
A+B- C+D+	111.9	68.3	48	41.2	270
A+B- C+D-	111.9	64.3	48	44.3	269
A+B- C- D+	111.9	64.3	55.4	38	270
A+B- C- D-	106.6	64.3	55.4	41.1	268
A-B+C+ D+	133.4	56.3	48	38	276
A-B+C+ D-	128	56.3	48	41.2	274
A-B+C- D+	128	52.3	55.4	38	274
A-B+C- D-	128	48.2	48	47.5	272
A-B- C+ D+	128	60	48	38	274
A-B- C+ D-	128	60.3	48.5	38	274
A-B- C- D+	122.7	64.3	51.7	34.8	274
A-B- C- D-	122.7	60.3	51.7	38	273

All simulation results of user data rates and total capacities under the sixteen kind of frequency estimating error were listed in Table 6. We can observe the ratios among user data rates are changed. It is reasonable because we assume the transmitter uses the generalized velocities and thus the estimated Doppler Frequency Shift as a part of fairness consideration. If the Doppler Spread from one user was underestimated, this user was granted more sub-carriers than ideal case. If the Doppler Spread from the user with least generalized velocity was underestimated, the user will be given more sub-carriers, and in effect, increasing the total capacity. We observe again that fairness and total capacity are trade-off in mobile OFDMA.

In Table 6 we can also observe the total capacity is quite robust to the frequency estimating error. We further discuss this phenomenon by two other cases. In Table 7, we use five cases of user generalized velocities to demonstrate the robustness of our algorithm against the estimating error. In Table 8, the robustness was demonstrated by the six scales of the estimating error.

In Table 7, the maximum deviation percentages from the theoretical total capacity under all estimating error types listed in Table 6 were computed, when the estimating error has been limited to $(0.1)f_d$. Noticing the first and second cases, when all users have the same generalized velocities, the total capacity does not change due to frequency estimating error. We can also observe that the total capacity become more robust to the frequency estimating error when the generalized velocities of all users are closer.

Table 7: Robustness of Our Algorithm against Estimating Error under Different Generalized User Velocities

Generalized User Velocity (km/hr) A	B	C	D	Maximum Deviation Percentage from Theoretical Total Capacity due to Frequency Estimating Error type Listed in Table 6
50	50	50	50	0%
60	60	60	60	0%
50	60	70	80	0.6%
30	60	70	90	1.61%
20	20	90	90	1.68%

From Table 8 we can see the proposed algorithm still can give a good result even the estimating error as large as $(0.5)f_d$. It can also be observed that the lower of the estimating error, the lower of the deviation from theoretical total capacity.

Table 8: Robustness of Our Algorithm against Different scales of Estimating Error

Estimating Error	Maximum Deviation Percentage from Theoretical Total Capacity due to Frequency Estimating Error type Listed in Table 6
$(0.01)f_d$	0.48%
$(0.1)f_d$	1.62%
$(0.2)f_d$	2.65%
$(0.3)f_d$	4.34%
$(0.4)f_d$	6.73%
$(0.5)f_d$	9.4%

V. CONCLUSION

In this paper we proposed a fair adaptive radio resource allocation algorithm for mobile OFDMA systems and demonstrated its robustness, which outperforms the algorithm without considering mobility. The priorities of users and fairness among users are incorporated into our algorithm by using the adaptation rule, and the fairness consideration has been demonstrated to be essential in mobile channels because of the trade-off between total capacity and fairness. We have demonstrated the criterion we used is more appropriate when considering mobility. We also demonstrated the proposed algorithm is very robust to the estimating error of the Doppler Spread Estimation.

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出席國際學術會議心得報告

計畫編號	NSC 95-2219-E-002-024-
計畫名稱	民生網路之前瞻研究-子計畫五:多標準共存之可調無線介接與正交分頻(1/2)
出國人員姓名 服務機關及職稱	陳光禎 台大電信所 教授
會議時間地點	2006.09.11 – 2006.09.14 芬蘭-赫爾辛基
會議名稱	The 17th Annual IEEE-International Symposium on Personal Indoor and Mobile Radio (PIMRC 2006)
發表論文題目	Fair Adaptive Radio Resource Allocation of Mobile OFDMA

一、參加會議經過

本人此次榮幸參加於芬蘭赫爾辛基舉行之 The 17th Annual IEEE-International Symposium on Personal Indoor and Mobile Radio (PIMRC 2006) 。PIMRC 自 1990 年起迄今每年舉辦一次，今年為第 17 屆。此次 PIMRC 的議題為「電信的多樣性」(Diversity in Telecommunications)，是由芬蘭的三所大學所主辦。會期自九月十一日至九月十四日，為期共四天。此會收錄超過 900 篇的論文，本人也發表了 1 篇論文，題目為 Fair Adaptive Radio Resource Allocation of Mobile OFDMA。此會另有口頭報告及海報展示，是相當成功且大型的國際研討會。

有 7 個 panel sessions:

1. Impregnating Wireless Communication into People’s Life
2. Ultra (UWB)
3. Mobile IP and Mobile TV: Trends and Strategies
4. Issues in Dynamic Spectrum Management
5. Trends and Challenges
6. Cooperative Techniques for Future Wireless Communication Systems
7. Applications of Wireless Sensor Networks

有 3 個 special sessions:

1. Global Research Activities on Future Broadband Wireless Systems

2. Flexible Spectrum Usage

3. Future Wireless Technologies

有 9 個 technical sessions(A-I):

A. Business, Services and Applications

B. 3G and WLAM Evolution

C. Ad-hoc and Sensor Networks

D. Network Management

E. Cellular Network Techniques

F. Transceiver Techniques

G. MIMO Systems and Techniques

H. Modulation and Coding

I. Physical Layer and Channel Modelling

二、與會心得

參與本次會議，主要是在於發表我們的研究心得，題目是「Fair Adaptive Radio Resource Allocation of Mobile OFDMA」，此篇論文被安排在 Track E: Cellular Network Techniques 的 Wireless Networks I 場次最後一篇，會議是由 VTT Electronics 的 Marcos Katz 主持。除了發表我們的研究成果，有機會和出席成員討論、吸取他們的意見，綜合如下：

1. 由會議的名稱與議程內容來看，本會議著重在一些最熱門的無限通訊技術之探討，如 Cognitive radio network, Ad hoc network, UWB, MIMO-OFDM，且涵蓋電信多項領域，切合會議主題:電信的多樣性。而來自世界各地學術界、產業界無線通訊領域的專家學者，互相交流討論意見，對於通訊領域專業知識的提昇，以及未來研究獲益良多。

2.在這次會議中，來自台灣的論文約有四五篇，分別來自台大（兩篇）、清大與成大（一篇）。雖然數量上並非大宗，但也顯示台灣在熱門的無線通訊領域中佔有一席之地。

The 17th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'06)

FAIR ADAPTIVE RADIO RESOURCE ALLOCATION OF MOBILE OFDMA

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Abstract - Orthogonal Frequency Division Multiple Access (OFDMA) is a promising technique which can provide high capacity in future communication systems. The total capacity of OFDMA can be maximized by dynamically allocating sub-carriers among users according to channel condition. However, it is quite challenging to properly allocate sub-carriers in mobile channels due to the time varying property. Existing approach designed for static users assigned the sub-carriers with the best SNR to increase the total capacity but to lose fairness. Fairness can be restored by using max-min criterion or constraint limiting the ratios of user data rates to maintain some balance among users. But when users are mobile, the SNR considered should be replaced by the carrier to interference ratio (CINR) because of the presented inter-carrier interference (ICI) due to Doppler Spread. In this paper we successfully incorporate the ICI into our radio resource allocation algorithm to simultaneously optimize the total capacity and fairness for mobile users. The fairness and priority of user traffic are jointly considered in our adaptive algorithm. The algorithm is demonstrated outperforms the existing algorithm designed for static users, and very robust in realistic operation.

I. INTRODUCTION

Wireless broadband communications become an extremely attractive research to transport multimedia traffic. To provide such high bandwidth physical transmission, one of the key design issues is to decide an appropriate multiple access scheme. Orthogonal frequency division multiplexing (OFDM) is widely considered for high-spectral efficient wireless communications, and has been adopted in wireless LANs, UWB, WiMAX, etc. To further utilize cross-layer radio resource, orthogonal frequency division multiple access (OFDMA) is widely considered in wireless broadband communications.

OFDMA is a multiple access technique inherited the ability of OFDM to combat inter-symbol interference (ISI), which can provide higher spectral efficiency by appropriate distributing radio resource [1]. Existing research include allocation of radio resource among static users for OFDMA systems [2] [3] [4] [5], and some of them considering fairness [4] [5]. Mobility has rarely been considered in literatures. In this paper we first incorporate the Doppler Spread into system optimization, and propose an algorithm to distribute the sub-carriers among mobile users to maximize total capacity and maintain fairness. Although the oscillator deviation, channel/environment variations and user's velocity all result in Doppler Spread we use generalized velocity to represent the combined effect of them.

The priority of each user was included as a part of fairness consideration which can be adaptively adjusted in our algorithm. We develop theoretical analysis and simulations to illustrate the advantages of the proposed algorithm over the static schemes without considering mobility. At last, we demonstrate our approach is quite robust to the frequency estimation which has been included for estimating Doppler Spread.

The organization of this paper is as follows. We first give the system model and formulate the radio resource allocation optimization for mobile OFDMA system in Section II. Some considerations were discussed in the same section. In section III, we give an experimental study to demonstrate the advantages of our algorithm over the existing static approach. In Section IV, we consider a more realistic case including Doppler Spread Estimator and demonstrate the robustness of our algorithm against the frequency estimating error. Finally we give some discussions and conclusion in Section V.

II. SYSTEM MODEL

A. *Analysis of ICI*

Inter-carrier interference (ICI) due to Doppler Spread results in the loss of orthogonality among sub-carriers. To include the mobility in our optimization, the ICI needed to be analytically analyzed [6].

Figure 1 depicts a discrete-time baseband equivalent model of OFDM system. b_s represent the source bits, symbol generator outputs symbols a_n. The serial to parallel converter transfers blocks of symbols to the OFDM modulator, which use an N-point IFFT to modulate them onto the sub-channels. A guard interval of length G is then be added to give a transmitted sequence corresponding to samples at $t = iT_s$

$$X_i^g = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} a_n \exp\left(j \frac{2\pi ni}{N} \right) \qquad 0 \le i \le N + G - 1 \tag{1}$$

where i and n are time and sub-carrier index. X_i^g is a sequence with guard interval.

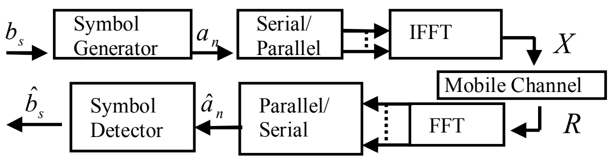

Figure 1: Communication System Using OFDM.

As [6], the received sequence from the multi-path channel has the form

$$R_i^g = \sum_{m=0}^{M-1} H_{m,i} X_{i-m}^g \qquad 0 \le i \le N + G - 1 \tag{2}$$

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where $H_{m,j}$ is the channel impulse response at path m and instant i. After removing the guard interval and demodulating by FFT, we can use the result of [7] [8] to separate the desired part and the ICI part of the received sequence in frequency domain as

$$\hat{a}_n = a_n S_0 + \sum_{l=0, l\neq n}^{N-1} a_l S_{l-n} + w_n \quad (3)$$

where

$$S_{l-n} = \frac{\sin[\pi(l-n+\varepsilon)]}{N \sin\left[\frac{\pi}{N}(l-n+\varepsilon)\right]} \exp\left[j\pi\left(1-\frac{1}{N}\right)(l-n+\varepsilon)\right] \quad (4)$$

is the ICI effect of sub-carrier n from the sub-carrier l in the same OFDM symbol. $\varepsilon = f_d / \Delta f$ is the normalized frequency offset. $f_d = v/c * f_c$ is the Doppler Frequency Shift due to user generalized velocity v and center frequency f_c, Δf is the sub-carrier space.

B. Optimization Formulation

We can formulate our optimization of radio resource allocation based on above mathematical form of ICI effect in mobile OFDM system. Figure 2 is the proposed OFDMA system. The Doppler Spread due to each user's generalized velocity was estimated by the frequency estimator, which will be further discussed in section IV. We assume all other channel information is known at the transmitter in this paper and introduce the proposed sub-carriers allocation algorithm.

There are K users in the system and the kth user has data rate equal to R_k bits per second. The serial data from the K users are fed into one sub-carrier allocation block which allocates sub-carriers to different users. We sssume the OFDMA system occupies total signal bandwidth B with N data sub-carriers and each data sub-carriers bandwidth is B/N. Maximum allowable total power for all users is P_{total}. Each of the K users has instantaneous generalized velocity v_k corresponding to Doppler Frequency Shift f_{dk} and thus normalized frequency offset ε_k.

Our objective is to optimize the sub-carriers allocation in order to maximize total capacity and maintain fairness among users under the total power constraint. We introduce the adaptation rule to be the fairness consideration. The benefit of introducing this rule is we can explicitly control the user data rates subject to system requirement.

Mathematically, the optimization considered in this paper is formulated as Equation (5). Where $P_{k,n}$ is the power assigned to user k's sub-carrier n, $h_{k,n}$ is channel gain on user k's sub-carrier n. The second constraint using the indicator $\omega_{k,n}$ to show that each sub-carrier can only be assigned to one user. N_0 is the power of additive white Gaussian noise (AWGN).

$$\max_{P_{k,n},\omega_{k,n}} \sum_{k=1}^{K}\sum_{n=0}^{N-1} \omega_{k,n} \log_2\left(1 + \frac{P_{k,n}|S_k(0)|^2 h_{k,n}^2}{P_{k,n}h_{k,n}^2 \sum_{l=0, l\neq n}^{N-1} |S_k(l-n)|^2 + N_0 \frac{B}{N}} \right) \quad (5)$$

Subject to

$$(i) \sum_{k=1}^{K}\sum_{n=1}^{N} P_{k,n} \le P_{total}, \; P_{k,n} \ge 0 \text{ for all } k,n$$

$$(ii) \sum_{k=1}^{K} \omega_{k,n} = 1 \text{ for all } n, \omega_{k,n} = \{0,1\} \text{ for all } k,n$$

$$(iii) \frac{R_k}{T} = \frac{f(p_k, v_k)}{\sum_{k=1}^{K} f(p_k, v_k)}$$

The user data rate R_k is defined as

$$R_k = \sum_{n=0}^{N-1} \omega_{k,n} \log_2\left(1 + \frac{P_{k,n}|S_k(0)|^2 h_{k,n}^2}{P_{k,n}h_{k,n}^2 \sum_{l=0, l\neq n}^{N-1} |S_k(l-n)|^2 + N_0 \frac{B}{N}} \right) \quad (6)$$

and T is the optimized total capacity. $f(p_k\ v_k)$ is a function of the user priority weighting p_k and the generalized user velocity v_k of the kth user. Which can be arbitrary selected for different relationship from user data rates to user priorities and user generalized velocities. The system designer may consider the fairness is both providing higher data rates for high priority users and giving lower data rates to high generalized velocity users when all users have the same priorities, or just granting the sub-carriers according to user priorities without considering generalized velocities. The definition of fairness can be controlled by the system designer.

The constraint *(iii)* is the adaptation rule we proposed for considering fairness which denotes the user data rates can be adaptively adjusted. We uniformly distribute $P_{k,n}$ among all sub-carriers in this paper because the total data throughout is close to total capacity even with flat transmit power spectral density [1] [12].

Equation (5) is the optimization of the adaptive fair radio resource allocation under mobile channels. This equation can be readily solved by standard numerical package such as AMPL [9]. Some differences between mobile and static environments will be discussed later.

C. Alternative Criterion and Constraint

In Equation (5), the criterion is to optimize the total capacity, but there is another criterion being used in static algorithm. Max-min criterion has been used to maximize the minimum capacity of all users and maintain some fairness among users. However, max-min approach is inappropriate for mobile channels, because the power of ICI is much greater than the additive noise [8]. If we maximize the minimum capacity, all users will be given almost equal data rates. It is inappropriate when different users have different priorities. It should be noted, the adaptation rule is essential, or the user with the least velocity gains all sub-carriers. Please note that, all users needed to be included in this constraint to avoid a user getting no sub-carrier allocation.

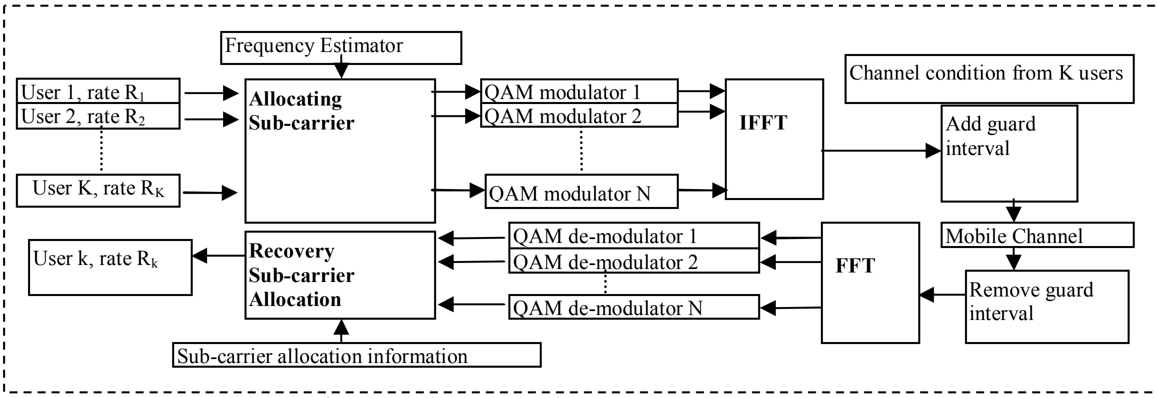

Figure 2: The Proposed OFDMA System

III. Experimental Study

In this section we consider an OFDMA system with 64 sub-carriers and 4 users (A,B,C,D). We select $f(p_k\ v_k) = p_k/v_k^z$ and and $z = 1$ in this and next section as an example. The generalized velocity of each user is assumed to be known at the transmitter as Table 1 in this ideal case. We consider a more realistic case in the next section.

Table 1: Generalized User Velocity in the Experimental Study

User	A	B	C	D
Generalized Velocity (Km/Hr)	30	60	70	90

We list the six cases we considered in this section. The simulation results were demonstrated in Table 2 and Table 3. 'L' and 'H' after the generalized user velocity denote user's priority. 'C_{total}' denotes the total capacity.

Case I : The proposed algorithm but without the adaptation rule (without considering fairness).
Case II : The proposed algorithm but the adaptation rule only include two users
Case III : Max-Min Criterion
Case IV : The proposed algorithm with all users have the same priorities ($p_A=p_B= p_C=p_D=1$)
Case V : The proposed algorithm with user C has high Priority. ($p_c = 3$ and $p_A=p_B=p_D=1$)
Case VI: The proposed algorithm with user C has higher priority ($p_c = 5$ and $p_A=p_B=p_D=1$)

Case I represents just maximizing the total capacity of all users, not taking account of user priorities and fairness among users. From the results we can see the user with the least velocity takes away all the sub-carriers. Giving the user with the least generalized velocity more sub-carriers in effect increasing total capacity, and the total capacity and fairness become trade-ff in mobile channels. Case II denotes we just include the maximum generalized velocity user and minimum generalized velocity user in the adaptation rule, and maximizing the total capacity. We can see only the user had been included in the adaptation rule get sub-carriers.

Table 2: Demonstrating the Necessity of Adaptation Rule and the Deficiency of Max-Min Criterion for Mobile Channels

	User A	User B	User C	User D	C_{total}
Case I	341.8	0	0	0	341.8
Case II	218.8(L)	0(L)	0(L)	72.9(L)	291.7
Case III	64.1(L)	63.3(L)	62(L)	60.3(L)	249.7

Case III changes the criterion to maximize the minimum capacity of all users. It seems some fairness among users was achieved, but user priorities have not been considered. It means even if the user C has high priority and the other users are low priority users, max-min criterion still gives the same result as case III which grants all users almost equal data rates and can not be adaptively adjusted.

Case IV is our proposed algorithm, maximizing total capacity with priority and fairness consideration. To demonstrate our algorithm is adaptive, case V and VI consider the cases when user C is high priority user and the other users are low priority users. By choosing $p_A=p_B=p_D=1$ and $p_C>1$, we can see the ratios of data rates among users can be adaptively adjusted in our algorithm.

Table 3: Simulation Results to Demonstrate the Adaptation for User Priorities of the Proposed Algorithm

	User A	User B	User C	User D	C_{total}
Case IV	122.7(L)	56.3(L)	51.7(L)	41.2(L)	271.9
Case V	83.6(L)	41.8(L)	108(H)	28(L)	261.4
Case VI	64.2(L)	32(L)	137(H)	21(L)	254.2

We then compare the proposed radio resource allocation algorithm to the static approach [4], which does not consider the mobility.

Table 4: Comparing the Adaptation of the Proposed Algorithm and the Static Algorithm

User		A	B	C	D
Velocity (km/hr)		30(L)	89(H)	90(H)	91(H)
Data Rate	Proposed	43	61	60	57
	Static	69	55	54	53
Velocity (km/hr)		30(L)	89(H)	90(L)	91(L)
Data Rate	Proposed	80	105	25	25
	Static	112	92	22	22

The results of comparison have been demonstrated in Table 4. Considering the first case, User B,C,D have high priorities, the system should give them higher data rates even they have higher generalized velocities. The proposed algorithm satisfies this requirement, but the static algorithm can not achieve that. In the second case we can see the same deficiency of the static algorithm. Although user B has high priority, the static algorithm still gives him lower data rate.

We have numerical demonstrated the differences between static and mobile algorithms. In the next section, we consider a more realistic case and discuss the frequency estimator in Figure 2.

IV. Robust to Physical Transmission

A. Frequency Estimator

We assumed the generalized velocity of each user is known at the transmitter in above ideal case. But in fact we need an estimator to estimate the Doppler Spread due to generalized user velocities. The frequency estimator in Figure 2 was used to estimate Doppler Frequency Shift.

B. Block Diagram

Earlier research already demonstrated effective estimation of Doppler Frequency Shift, which is shown in Figure 3 [10] [11]. Consequently, it is enough to consider random behaviors of frequency estimation in studying the proposed algorithm.

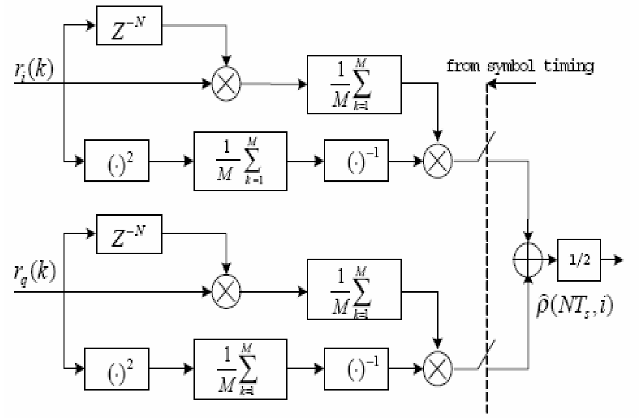

Figure 3: Block Diagram of Frequency Estimator

C. Evaluating the Effect of Estimating Error

The estimating error from frequency estimation introduces several effects. First, the fairness among users considered in the adaptation rule was assumed to closely relate to the user generalized velocities and thus the estimated Doppler Frequency Shift. The estimating error destroys fairness. Furthermore, the Doppler Frequency Shift has been used to allocate sub-carriers; the estimating error may influence the total capacity. For simulating those effects, we consider an OFDMA system with four users and 64 sub-carriers at f_c = 3.2 GHz. All users are assumed to have the same priority but different generalized velocities. The error of estimation is normalized to the theoretical Doppler Frequency Shift f_d.

Table 5 list the configuration we used in simulation to evaluate the effect of estimating error. The first line is user generalized velocity v_k (Unknown to Transmitter); the second line is the theoretical Doppler Frequency Shift f_{dk} under those generalized velocities. We first choose the estimating error equal to $(0.1)f_{dk}$ to give a detail analysis of the effect of estimation, and then we further discuss the conditions for larger estimating error.

Table 5: Configuration to Evaluate Estimating Error

User	A	B	C	D
Velocity (v_k :Km/Hr) (Unknown to Tx)	30	60	70	90
Ideal Doppler Frequency Shift under above Generalized User Velocity ($f_{dk} = v_k/c*f_c$ Hz)	89	178	207	267
Estimating Error $(0.1)f_{dk}$	8.9	17.8	20.7	26.7

Under the scale of estimating error, we list all types of frequency estimating error and the simulation result in Table 6. "+" after user k denotes the estimator overestimate the f_{dk} by $(0.1)f_{dk}$ and "-" after user k denotes the estimator underestimate the f_{dk} by $(0.1)f_{dk}$. 'C_{total}' denotes total capacity and 'Ideal' denote the ideal case considering the theoretical Doppler Frequency Shift.

Table 6: Simulation Results to Evaluate the Frequency Estimating Error under Sixteen Error Types

Error type	User A Data Rate	User B Data Rate	User C Data Rate	User D Data Rate	C_{total}
Ideal	122.7	56.3	51.7	41.2	272
A+B+C+D+	117.3	60.3	51.7	41.2	271
A+B+C+D-	117.3	56.3	51.7	44.3	270
A+B+C- D+	111.9	56.2	59.1	41.1	269
A+B+C- D-	111.9	56.2	55.4	44.3	268
A+B- C+D+	111.9	68.3	48	41.2	270
A+B- C+D-	111.9	64.3	48	44.3	269
A+B- C- D+	111.9	64.3	55.4	38	270
A+B- C- D-	106.6	64.3	55.4	41.1	268
A-B+C+ D+	133.4	56.3	48	38	276
A-B+C+ D-	128	56.3	48	41.2	274
A-B+C- D+	128	52.3	55.4	38	274
A-B+C- D-	128	48.2	48	47.5	272
A-B- C+ D+	128	60	48	38	274
A-B- C+ D-	128	60.3	48.5	38	274
A-B- C- D+	122.7	64.3	51.7	34.8	274
A-B- C- D-	122.7	60.3	51.7	38	273

All simulation results of user data rates and total capacities under the sixteen kind of frequency estimating error were listed in Table 6. We can observe the ratios among user data rates are changed. It is reasonable because we assume the transmitter uses the generalized velocities and thus the estimated Doppler Frequency Shift as a part of fairness consideration. If the Doppler Spread from one user was underestimated, this user was granted more sub-carriers than ideal case. If the Doppler Spread from the user with least generalized velocity was underestimated, the user will be given more sub-carriers, and in effect, increasing the total capacity. We observe again that fairness and total capacity are trade-off in mobile OFDMA.

In Table 6 we can also observe the total capacity is quite robust to the frequency estimating error. We further discuss this phenomenon by two other cases. In Table 7, we use five cases of user generalized velocities to demonstrate the robustness of our algorithm against the estimating error. In Table 8, the robustness was demonstrated by the six scales of the estimating error.

In Table 7, the maximum deviation percentages from the theoretical total capacity under all estimating error types listed in Table 6 were computed, when the estimating error has been limited to $(0.1)f_d$. Noticing the first and second cases, when all users have the same generalized velocities, the total capacity does not change due to frequency estimating error. We can also observe that the total capacity become more robust to the frequency estimating error when the generalized velocities of all users are closer.

Table 7: Robustness of Our Algorithm against Estimating Error under Different Generalized User Velocities

Generalized User Velocity (km/hr) A	B	C	D	Maximum Deviation Percentage from Theoretical Total Capacity due to Frequency Estimating Error type Listed in Table 6
50	50	50	50	0%
60	60	60	60	0%
50	60	70	80	0.6%
30	60	70	90	1.61%
20	20	90	90	1.68%

From Table 8 we can see the proposed algorithm still can give a good result even the estimating error as large as $(0.5)f_d$. It can also be observed that the lower of the estimating error, the lower of the deviation from theoretical total capacity.

Table 8: Robustness of Our Algorithm against Different scales of Estimating Error

Estimating Error	Maximum Deviation Percentage from Theoretical Total Capacity due to Frequency Estimating Error type Listed in Table 6
$(0.01)f_d$	0.48%
$(0.1)f_d$	1.62%
$(0.2)f_d$	2.65%
$(0.3)f_d$	4.34%
$(0.4)f_d$	6.73%
$(0.5)f_d$	9.4%

V. Conclusion

In this paper we proposed a fair adaptive radio resource allocation algorithm for mobile OFDMA systems and demonstrated its robustness, which outperforms the algorithm without considering mobility. The priorities of users and fairness among users are incorporated into our algorithm by using the adaptation rule, and the fairness consideration has been demonstrated to be essential in mobile channels because of the trade-off between total capacity and fairness. We have demonstrated the criterion we used is more appropriate when considering mobility. We also demonstrated the proposed algorithm is very robust to the estimating error of the Doppler Spread Estimation.

VI. References

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