UWB Report 2

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***Abstract*—In this report we focus on the Exclusion region of UWB wireless network. Based previous works, we studied the ideas of joint optimization in UWB wireless network MAC protocol design. We learned that exclusion region plays very important part in joint optimization. Beside the most important factor: the maximized transmission power, there are also some other factors that affects the exclusion region for joint optimization. In this report we studied the property of these factors and give basic formulation of them. In our future work we will make simulations to see whether the analysis meet the real applications.**

I. Introduction

A. Ultra-Wide Band

Wireless communication is everywhere and it is playing a more and more important role today. Thus emerging networks assume the deployment of large numbers of wireless nodes, embedded in everyday life objects. In most cases, it is important that the radiated energy be kept very small so that it dose little harm to people's health. And at the same time high data rates are required. Ultra-wideband (UWB) wireless networks have the potensial to satisfy both requirements.UWB technology is a short-range radio technology which is ideal for wireless personal area networks (WPANs). As per the specifications of FCC, UWB communications use the spectrum from 3.1 GHz to 10.6 GHz [1]. It provides the needed cost-effective, power-efficient, high bandwidth solution for relaying data from host devices to devices in the immediate area (up to 10 meters or 30 feet). UWB differs substantially from conventional narrowband radio frequency(RF) and spread spectrum technologies(SS), such as Bluetooth* Technology and 802.11a/b/g.UWB radio is an emerging wireless physical layer technology that uses a very large bandwith. It is becoming a promising field for new generation's digital communication systems. UWB systems are mostly based on impluse radio technology, which has recently reached an appreciable degree of development to be able to support high data rates with low power consumption and low complexity in terms of transmission/reception operations[1]. UWB is a promising field to creat small and high bit rate transceivers that could be used for many applications, from wireless local area networks(LANs) to ad-hoc networks, from IP mobile-computing to multimedia-centric applications.

B. MAC for UWB

In UWB communication systems, there may be more than one wireless devices needed to enter into the channel which leads to collisions between groups. Meanwhile, because UWB has the features such as a wide band, high speed rate and low power spectrum density, it is difficult for the receiver to make out the data it received. Thus, it results in severe channel resource waste and obvious decrease of throughout. Under this circumstance, designing an appropriate MAC Protocol is crucial to UWB.

C. MAC protocol design on UWB–Joint Optimization

There have been many protocol design of MAC on UWB. Some focused on the properties of the sending and receiving nodes; some focused on the synchronization and asynchronization; some focused on the transmission power and some on the packet size and rate.

However, all the methods mentioned above are not good enough because it has recently become evident that a traditional layering approach that separates routing, scheduling, fbw and power control might not be efficient for ad-hoc wireless networks. There are inherent relationships between them. To get better results, jointly optimal routing and MAC strategies must be considered rather than focus on one separate aspect. Here we formulate our question as that of a joint optimaization of power control, scheduling and routing. With Joint Optimization, we can make trade-offs between each point to get a optimal result over all. There are already some papers that study the joint optimization problem. The corresponding references are [2-6].

D. Exclusion region

The research of exclusion region is a branch of the research on scheduling. when data is being sent over a link, it is optimal to have an exclusion region around the destination, in which all nodes remain silent during transmission, whereas nodes outside of this region can transmit in parallel,regardless of the interference they produce at the destination. Additionally, the source adapts its transmission rate according to the level of interference at the destination due to sources outside of the exclusion region.In [7] the authors point out that the size of the exclusion region depends only on the transmission power of the source of the link, and not on the length of the link, nor on positions of nodes in its vicinity.Hence the exclusion regions are going to be larger if nodes use direct routes instead of next-hop routes.

E. Our works

In this report,we focus on the exclusion region mechanism of networks .We will explain much clearly what exclusion region is and how important a role it plays in decrease interference. **In our opinion**, the transmission power is not the only concentration for the exclusion region; the other factors such as mobile node distribution and different level of power constrains will also affects the exclusion region, our research is motivated by this. We try to find the relation of other factors with the size of the exclusion region. Based on the two factors mentioned above, we setup 3 scenarios to study the affection to the exclusion region. Also we will give some mathematical derivation as well.

The rest of this paper is organized as follow: Section II is the detailed analysis of Exclusion Region; Section III is the mathematical formulation of Exclusion Region, Section IV is our research of affections from different factors to the Exclusion Region; We summarize our current work and defined further research area: the Matlab and ns2 simulations.

II. Exclusion region

A. Definition

The MAC layer globally manages the interference and medium access on a shared communication channel. Its main goal is to maximize in a fair manner both the overall lifetime of the network and the rate offered to each node. One of the most important function the MAC layer provide is inference management. Most traditional MAC protocol use the mutual exclusion mechanism to achieve this objective.

An exclusion region is a region around each receiver such that no interferers exist inside this region. In the exclusion region, all nodes remain silent while the nodes outside the exclusion region could transmit data in parallel.

In [8], the size of the exclusion region (referred to in the paper as critical radius), is investigated for CDMA networks. It is shown that large performance improvements are possible in a CDMA system by employing an exclusion region and it is suggested that there exists an optimal size for the exclusion region that maximizes transmission-capacity.

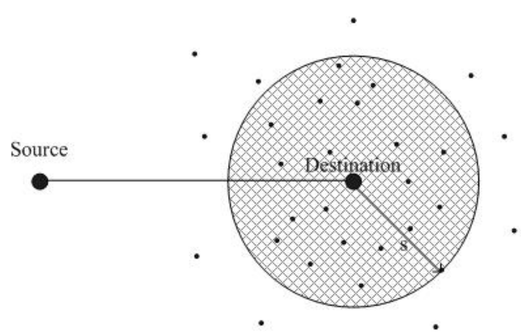

Fig. 1. A basic example about exclusion region

For the critical radius D=0, the performance of outage is not so good both for FH-CDMA and DS-CDMA, and therefore constraints the transmission capacity.

We can see the outage probability for both CDMA systems as a function of the critical radius (normalized by the transmission range,) i in the following figure.

The performance for both systems improves with the introduction of the guard zone and this is quite intuitive since employing a guard zone reduces the probability of a close by interferer. What is interesting is that DS-CDMA results in better performance when D Do, whereas without a guard zone, it never exceeds FH performance. This reduction in outage probability, at the expense of inhibiting few close by transmissions, may result in higher throughput.

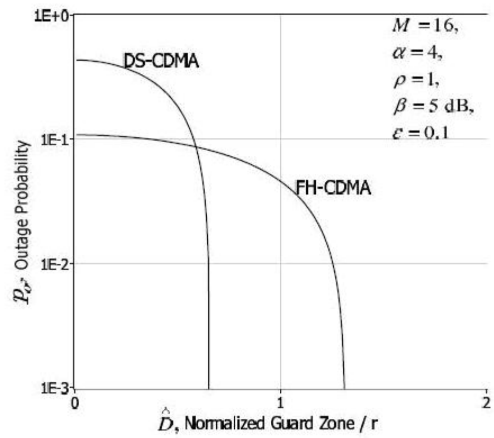

Fig. 2. comparison of outage probability

Also, we can see the size of exclusion region has a large impact on the performance of the adhoc network. In a spectrum-sharing ad hoc network[9], it can be seen that the sum interference power decreases with an increase in the radius of the exclusion radius. However, it also can be seen that the density of nodes decreases with an increase in exclusion radius due to the physical constraint in the number of circles of a given radius that can be accommodated in a given area. Therefore, there exists an optimum exclusion radius that maximizes the sum outage-capacity of the network. Alternatively, if the SINR required for a user-pair transmission is kept constant, it can be seen that an increase in exclusion radius increases the density of nodes that can be accommodated in the system for a specific outage-probability. However, as mentioned above, the density of nodes decreases with an increase in exclusion radius due to physical constraints. Hence for a given outage probability and outage-capacity for a user-pair, there exists an optimum exclusion radius that maximizes the transmission density of the network.

We can see that exclusion region is a good method for designing a efficient MAC protocol through maintaining a desired Signal to Interference Ratio (SINR) at the receiver.

III. Mathematical Formulation of Exclusion Region

In Section II we give the definition of exclusion region and its significance to the performance of UWB. In this section we will translate exclusion region into a numerical problem. We will express the exclusion region in mathematical way in order to have a better analyze of it.

A. Assumptions and Notations

In order to get the mathematical expression of exclusion region , first we have to make some assumptions and notations.

1) Notations: We model the wireless network as a set of *I* flows, *L*links,*Q* nodes and *N* time-slots. Flows are unicast or multicast. We give here a list of notations used in this section to describe the model.

- $f \in R^I$ is he vector of average rates achieved by flows.
- $x \in R^L$ is the vector of average rates achieved on links.
- for every $n \in \{1, 2, .., N\}$, $x^n \in R^L$is the vector of rates achieved on links in time slot n
- for every $n \in \{1, 2, .., N\}$, $p^n \in R^L$, $p^n_{rcv} \in R^L$ are the vectors of transmitted and received powers allocated on links in time slot n, respectively.
- $P^{MAX} \in R^L$ is the vector of maximum allowed transmission power on links, which are assumed constant in time (every link may have a different maximum power).
- $\eta \in R^L$ is the white noise at a receiver, and is assumed constant for all links in time.
- for every $n \in \{1, 2, .., N\}$, $SNR^n \in R^L$ is the vector of signal-to-noise ratios at the links receivers in time slot n.
- R (routing matrix) is such that $R_{l,i} = 1$ if flow i uses link l. We have $f \leq R\bar{x}$. The matrix R is defined by the routing algorithm.
- $h_{l1,l2}$ is the attenuation of a signal from the source of link l_1 to the destination of link l_2.

B. Physical Network Model

In our paper , the whole process is based on a specific network model. In this section we choose Win-Scholtz physical model [10] which we use latter as an example to illustrate our modeling assumptions. And according to [7],this model is valid for large variety of UWB physical layers.

a) The Win-Scholtz Physical Model: Just like in paper [7]We also assume that the physical layer is based on the ultra-wide band radio described in [10]. This radio is based on pulse position modulation (PPM) and a coherent receiver.

Time is divided in frames of duration T_a . Each frame is divided into bins of duration T_c. A node transmits one pulse per frame, and it has a pseudo-random time hopping sequence that tells it in which bin to transmit. Having chosen a bin, the node sends a very short pulse within the duration of the bin. If it is sending a logical zero, this pulse is sent at the beginning of the bin, and if it is sending a logical one, the pulse is delayed by δ On the example on Fig. 1, the first pulse carries zero, and the second carries one.

Time hopping is used to achieve multiple access. The source and the destination of each link have a common pseudo-random time hopping sequence that is independent of other links' sequences. For other users not knowing the time hopping sequence, this signal has the statistical properties of Gaussian noise, due to randomness in time-hopping codes. It has been shown that for the particular receiver used in [10], the total noise received, comprised of background noise and a sum of signals from other active links, will be perceived by the decoder as a Gaussian noise.

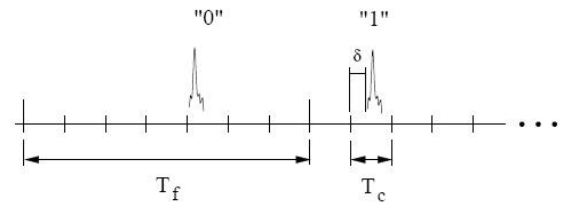

Fig. 3. UWB physical layer with PPM, the model of Win Scholtz [33].

C. The Enducement of the Expression for Exclusion Region

From [11]an d [12] we have

$$prcv^n_l = p^n_l K_\alpha d_l^{-\gamma} \tag{1}$$

where $p_{rcv}$is the received power of link l at time slot n. K_α and γ are constants. K_α stands for how much the amplitude of the received power is affected after the transmission process. γ stands for the attenuation index which indicates that the attenuation is an exponentially decreasing function related to the distance from the source to the destination. This equation vividly describes the power attenuation and is close to the realistic cases. Hence it is widely used in lots of numerical models. And we also use it in our report.

Here we write the equation in a different form:

$$prcv^n_l = p^n_l h_{ll} \tag{2}$$

where $h_{ll} = K_\alpha d_{l-\gamma}$.
From [12] and [13] ,the maximal achievable rate is a linear function of SNR at the receiver. Thus,we have

$$x^n_l = K \times SNR^n_l \tag{3}$$

This equation holds for Win-Scholtz model as well as a lot of different UWB models. So we can apply it to our report to further enduce the exclusion size.

The equation(3) holds on the condition that a desired bit-error rate is given. According to[14], when the desired bit-error rate *P(e)* is fixed,we have that

$$K' = N_s * E_x/\eta \tag{4}$$

Since $SNR = E_x/\eta$ is the signal-to-noise ratio of the received symbol where E_x is the average received power of a symbol, and the rate $x^n_l = 1/N_s N_f$ putting it into equation (3), we have $K = 1/K' T_f$,which is a function of bit-error rate and the length of time-hopping sequences.

From[15], we know that for very large bandwidth parallel transmissions become completely orthogonal and do not interfere with each other. However, in the case of finite bandwidth system it is never the case.Hence We introduce an orthogonality factor β that models how much of wide-band interference is captured by a receiver. The specific value of the orthogonailty factor depends on the implementation of a UWB system. In the case of Win Scholtz[10] model, as shown in [14], this factor is of the order of $1/T_f$.

If η is the white noise at a receiver, and Z is the total interference from other sources, then the effective noise observed through the decoding process is $\eta + Z$. and the rate of link in slot n is:

$$x_l^n = K \times \frac{p_{ll}}{\eta + \beta Z} \tag{5}$$

[7]. And without loss of generality, we can assume β =1.

In our UWB physical layer model, data are sent in packets, and the rate of each packet is given by (3), which is a function of the average packet sending power p_l^n. It is the average power of symbols in the codebook used in n slot, according to [7],we temporarily assume it is limited by $p_l^n \leq p_l^{MAX}$ due to various hardware and regulation constraints, and it is assumed constant in time. But in fact there may be more than one threshold on the maximum transmission power, namely, not all the nodes in a network are constrained to not to exceed the single P^{MAX} . The detail is shown in section 4.

In a network, Consider the destination node D of link F, and assume it has an exclusion region of radius s. We assume N(s) a number of nodes that are in the exclusion region of D, and I(s) is the interference received by D if all nodes outside of the exclusion region would be active at the same time at the maximum power.

Link l can be scheduled for transmission at approximately every $k_1 N(s)$ slot. When scheduled, it will experience the interference of approximately $k_2 I(s)$, where k_2 models the fact that not all the nodes outside of exclusion region will be scheduled at the time. The rate of link l in this case is:

$$\bar{x}_l = \frac{K}{k_1 N(s)} \frac{P_l^{MAX}}{\eta + k_2 I(s)} \tag{6}$$

In [the 19-page paper given by xwang8],the author assumes that the nodes all the factors except the transmission power are fixed. Thus, by the first derivative of eqution(6) they got:

$$s = (\frac{(\gamma - 2)P^{MAX}}{2\eta})^{1/\gamma} \tag{7}$$

Under this circumstances, they drew the conclusion of the optimal exclusion size with the maximal transmission power constraint. But other factors may also have impacts on the exclusion region other than the maximized transmission power. In the next section we are trying to find out the relation of those factors.

IV. Analysis of the Factors of Exclusion Region

In previous research the maximized transmission power is considered most. this is because the basic property of UWB radio shows that the SNR is proportional to the transmission power. Equation (6) is used to study the the exclusion region in [7]. In their research they assume that the distribution of the mobile nodes follows a uniform distribution; and all nodes have the same power constrains. The relation of the maximized transmission power with exclusion region satisfied equation(7).

But in our point of view, the Pmax is not the only concentration of the exclusion regiond; the other factors such as mobile node distribution will also affects the exclusion region, our research is motivated by this. We try to find the relation of other factors with the size of the exclusion region.

Beside the uniformly distributed nodes with homogeneous environments, in some non-homogeneous environments the other factors play very important part.

- ***mobile node distribution:*** the distribution of mobile node is one of the key factor that affects the exclusion region. the uniform distribution is the most easy one in analysis but in real world each mobile node have own tendency and preferences, they seldom follows the uniform distribution. A typical scenario is the wireless users in campus, most of them prefer to use their laptop in teaching buildings or libraries, because they still need some power supply.
- ***Non-homogeneous Power Constrains:*** the power constrains is another important factor that affects the exclusion region. It is obviously that wireless cards in laptops have greater power constrains than the ones in handhold devices such as PocketPC and BlackBery. We proposed that several different level of power constrains classification is needed.
- ***Non-homogeneous traffic model:***If there exists one or more base stations the situation will be much different. This scenario has the property of both two factors. The traffic to and from the base station is the major traffic rather than mobile ndoes, the base station also have higher power constrains, and in order to get better signal the mobile nodes will prefer to stay near the base station.

Based on the analysis above we can see that in real world there are some complicated factors that affects the exclusion region. We here assume that the exclusion region for different receivers might be different according to different environments around the receiver; which does not like in [7], where they assumed that the exclusion region is fixed since they consider the factor of the maximal transmission power only.

In order to study the different affection of these factors we setup 3 scenarios corresponding to the previous analysis.

- The first scenario is in the open fields where the mobile nodes are randomly distributed in one square, and in order to simplify the analysis difficulty in this scenario we assume that all the nodes have the same power constrains. We use $\lambda(x, y, s)$ to represent the node density inside a circle area with center point(x,y) and a radius of s, so the number of total nodes inside the exclusion region will become:

$$N(s) = s^2 \pi \lambda(x, y, s) \tag{8}$$

Now if we inspecting the first derivative the radius s of the exclusion region will satisfy a new equation:

$$(\frac{\eta}{P^{MAX}}+s^{-r})\frac{\partial\lambda(x,y,s)}{\partial s}=(\gamma-\frac{2\eta}{P^{MAX}s})\lambda(x,y,s)+s^{-r-1} \tag{9}$$

- The second scenario considers the different level of power constrains, we assume there are two kind of devices with different power constrains level the small one is P_1^{MAX} and the bigger one is P_2^{MAX}, δ will be the ratio of the number of the two devices: $\delta=\frac{num(P^1)}{num(P^2)}$; so the average maximal transmission power will be:

$$P^{MAX}=P_1^{MAX}\times\frac{\delta}{1+\delta}+P_2^{MAX}\times\frac{1}{1+\delta} \tag{10}$$

In order to simplify the analysis we also assume that all the nodes are uniformly distributed in the whole area.
In this scenario the *I(s)* in equation(6) is changed to:

$$I(s)=(P_1^{MAX}\times\frac{\delta}{1+\delta}+P_2^{MAX}\times\frac{1}{1+\delta})s^{-\gamma} \tag{11}$$

The affection is easy to see, when we inspecting the first derivative again we got:

$$s=(\frac{(\gamma-2)(P_1^{MAX}\times\frac{\delta}{1+\delta}+P_2^{MAX}\times\frac{1}{1+\delta})}{2\eta})^{1/\gamma} \tag{12}$$

it is easy to see how the ratio δ affects the radius of the exclusion region while other factors are fixed. the figure below shows the affection which is very interesting.

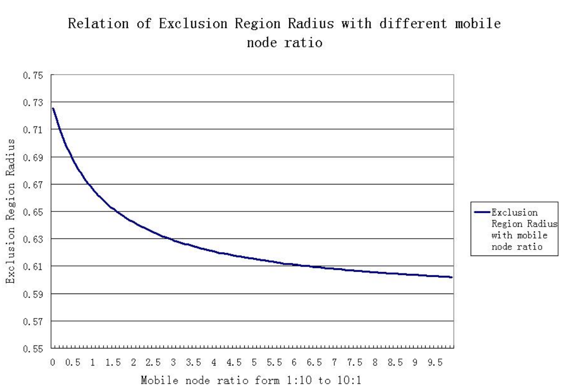

Fig. 4. The relation of Exclusion Region Radius with different mobile node ratioδ

- the last scenario is the most complicated part, in this scenario we have a base station in the middle of the square area, at this time the distribution of the mobile nodes is not irregular anymore, they are preferred to stay near the base station in order to get better signal, the distribution is proportional to the signal strength or the attenuation function. We assume the node density is only the function of the distance *R* to the base station; and the density follows this equation $\lambda=\theta R^{-\gamma}$ as it is shown in Fig.x The power constrains at base station is much greater than the regular mobile nodes, we assume it is P_{base}^{MAX}, we assume all the other mobile nodes have the

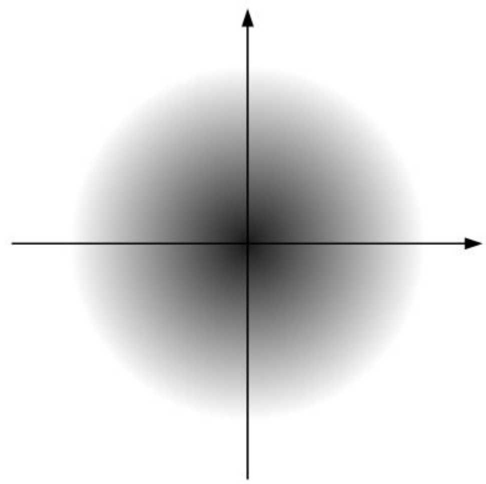

Fig. 5. the node distribution habit with base station

same power constrains of P'^{MAX}. Since there is only one base station and a great amount of mobile nodes the average power constrains may still be P'^{MAX}.
Followed by the assumptions in this scenario the the N(S) is modified to:

$$N(s)=\int\int_{|\vec{r}|\leq s}\theta R^{-\gamma}d\vec{r} \tag{13}$$

As is shown in Fig.5 below.

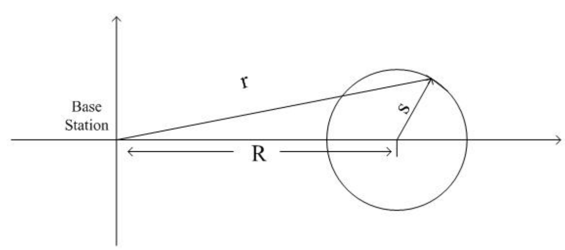

Fig. 6. How to calculate N(s) in our scenario

By inspecting the first derivative to equation (6) once more, we get:

$$(\frac{\eta}{P^{MAX}}+s^{-r})\frac{\partial N(s)}{\partial s}=(\gamma-\frac{2\eta}{P^{MAX}s})N(s)+s^{1-r} \tag{14}$$

In this section we only give the formulation of these factors, the detailed simulations on matlab and NS2 will be carried out in the next report, from them we can have a deep sight of the affection of these factors

V. Project progress and further work

Since the submission of last report, we continued reading papers about UWB, try to choose a topic to make further research, one of our finding is that the power consumption is one of the most important thing in wireless networks, the limited power supply limited the mobility of mobile terminals, so how to optimize the power consumption is very important. Another thing we learned is that sometimes concentrate in optimizing one factor may do harm to the whole system performance, so the recently advanced joint optimization method is of great value.

In our research we do investigation of the factors other than the maximized transmission power such as node density and different level of power constrains. And show the formulations and some preliminary results.

The main reference of our report is "Božidar Radunović, Jean-Yves Le Boudec, Optimal Power Control, Scheduling and Routing in UWB Networks, IEEE JSAC" They do very great job in their 19-page length paper, from it we learned a lot of things about UWB wireless network design from Physical layer to MAC protocol to routing desing. Based on these findings we start to study the exclusion region in UWB wireless networks, as the exclusion region plays critical part in joint optimization design.

They also shared their matlab codes on the web, it takes some time for use to read and fully understand the code, the reading itself also helps up to get deep understanding of the paper itself.

In the next we are going to use Matlab and NS2 to make simulations based on our assumption, formulations and the preliminary results.

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