

Designing a CDD/TDD-CDMA Network Architecture

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Abstract— Code division duplexing (CDD) has steadily garnered attention in the telecommunication community. In this paper we propose a physical layer implementation of CDD that utilizes orthogonal gold codes as the means of differentiating transmission directions, in order to implement an ad-hoc networking infrastructure that is overlaid on a standard mobile networking topology, and hence creating a hybrid networking topology.

I. INTRODUCTION

WITHIN recent years there has been a tremendous growth in mobile network usage. However, regulatory bodies actively control the limited radio frequency spectrum and the allocation of radio spectrum has become an expensive and complex ordeal. As a consequence, there exists the drive to use more spectral efficient techniques in order to accommodate more users per hertz, or simply more users.

In frequency division multiple access (FDMA) based 2G mobile networks, frequency reuse planning remained one of the primary ways of increasing spectral efficiency. Technologies such as GPRS (for GSM) and EDGE enabled the 2G mobile networks to persevere despite the increased user base and increased user demand for content other than voice access.

3G networks have the benefit of using a more spectrally efficient access technology, Code Division Multiple Access (CDMA). CDMA based mobile networks have the advantage to carry more calls per hertz allocated, however, one of the disadvantages of using CDMA as the physical access scheme is that its performance degrades when more users are introduced to the system. This phenomenon is known as multiple access interference (MAI). MAI occurs in CDMA based systems as a result of all the users sharing a single frequency band, and at the same time each user is usually providing the same amount of interference power. As defined in [9], the bit error performance for a single user can be approximated by:

$$P_e = Q\left(\sqrt{\frac{3 \times \text{spreading factor}}{\text{users} - 1}}\right)$$

Therefore, as more users are introduced, the bit error rate increases and as a consequence it becomes difficult to recover a transmission to an intended receiver.

Other than the combination of medium access techniques, such as FDMA-CDMA, that reduce the MAI, there are hybrid network topologies that can increase the overall network throughput. Of the hybrid topologies that have garnered the attention, ad-hoc networking with infrastructure support is most popular.

II. BACKGROUND

Within the 3GPP specification there is an extension to UMTS Terrestrial Access Network Time Division Duplexing (UTRAN-TDD) mode known as Opportunity Driven Multiple Access (ODMA). ODMA is inherently a hybrid topology protocol, because it allows for mobile stations to either communicate with the base station or with another mobile station in the vicinity. Although the standard has been abandoned by the standardization body there is research that demonstrates the benefits of ODMA.

It has been shown in [7] that in ODMA based TDD-CDMA networks, there is an increase in the capacity of the network and that simple ODMA will lead to a reduction to the overall power consumption of user equipment. The project also showed that multi-hop communication amongst peers attributed to the reduction of power consumption. In addition, ODMA has been shown to extend the coverage limit of a cell in UTRA TDD [8].

It was shown in [13] that an ad-hoc overlay on a (2G based) network with infrastructure support, in which TDMA was used as the access mechanism, that the systems capacity was increased. To take another perspective, it has also been shown that ad-hoc networks that are given infrastructure support will also benefit from an increase in capacity, as demonstrated in [10].

Clearly, the synergy of the two networking topologies promises to provide capacity and even coverage benefits. That being the case, this project proposes a physical layer hybrid topology architecture using code division duplexing to differentiate between peer-to-peer traffic and traffic between the network and the mobile station. The architecture also includes the use of time division duplexing (TDD) to provide the means of differentiating the uplink from the downlink.

The motivation for the system's architecture is to potentially create a mobile system that will be well suited for the African environment on more than one level, i.e. suited for sparse user densities but can accommodate high user densities; and financially viable. From the perspective of the cost to the consumer TDD has intrinsic benefits. TDD systems have been shown to consume less power, to have

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higher spectral efficiency, and are better suited for power control [5]. Power control is simplified as well. Seeing that TDD systems use the same frequency for the uplink and downlink, frequency selective characteristics can be estimated for both uplink and downlink; and as a consequence, only open-loop power control is required in a TDD based CDMA system. In addition, TDD system based terminals are cheaper to produce en masse primarily due to the fact that they do not require complex frequency duplexers [6].

Another favourable attribute to TDD systems is that it can easily accommodate asymmetric data traffic. Time slots can be dynamically allocated for uplink or downlink to allow for change in throughput required in either direction. For example, in a voice conversation, equal time slots can be allocated for uplink and downlink; whereas in a web-surfing session, more time slots will be allocated to the downlink seeing that the uplink carries considerable less data (control and requests data).

The ad-hoc component of the proposed architecture potentially compensates for the inherent lack of coverage in TDD systems. On a similar note, an extension in coverage would present a cost benefit to network providers. It would decrease the need to put a high number of base station repeaters in their target service areas.

III. RELATED WORK

The hybrid network topology, presented in [1], displayed an increase in throughput of a cell while at the same time increasing a single user's throughput by up to 310%. However, the architecture proposed in this case is based on the synergy of two wireless technologies, CDMA2000 and IEEE 802.11b. This would require mobile terminal to have two radio interfaces.

The above project is based on using two radio interfaces, which will be more expensive than an implementation that uses a single interface. Another disadvantage of devices that use multiple radio interfaces is that the terminals' ephemeral power supply is overly encumbered by the two interfaces. In addition, radio coverage planning becomes complicated when multiple radio interfaces are used in the same system. This is because the mobile channel fading statistics that determine path loss are influenced by the transmission frequency and bandwidth of the transmitted signals. Unlike, the system just mentioned, TDD based CDMA systems benefit from simple radio coverage planning.

Mentioned earlier, work done in [7] and [8] demonstrated the improvements in performance that TDD based CDMA systems will incur when hybrid topologies are implemented.

IV. CODE SEQUENCES

In deciding what the set of code sequences that are needed to implement a CDD based system, it is necessary to comprehend the properties of the code sequences that could potentially form the basis of a CDD system.

Pseudo-noise (PN) sequences are binary sequences that resemble a (truly) randomly generated sequence over a period; also the autocorrelation of a PN sequence resembles that of the autocorrelation of band limited white noise. In

fact, after the spreading of a signal is complete, the energy distribution along the frequency domain is uniform and resembles Gaussian white noise [9]. PN sequences can be generated from basic simple feedback shift registers which are easily implemented in hardware. One of the characteristics of PN sequences is that, on average, it has an equal amount of ones and zeros throughout the sequence. A feedback shift register with m -stages can produce a PN sequence with a maximum length of 2^m-1 bits. Maximum length sequences are referred as m -sequence and are used over non- m -sequences for spreading.

Because of the excellent autocorrelation properties of PN m -sequences, they are preferred for synchronization. However, pseudo-noise m -sequences can have pronounced cross correlation maxima and thus it was necessary to find a set of PN sequences that has the properties to mitigate the disadvantages of PN m -sequences.

Gold codes are PN sequences that have more favourable cross correlation properties with slightly reduce autocorrelation performance. Gold codes are created from two parent PN sequence generators with favourable cross correlation properties. One of the sequences is set to an offset and the resulting bits are combined by way of a logic XOR operation, as shown in figure 1. Like PN sequences, the maximum length of Gold codes is 2^m-1 bits, where m represents the number of stages in both of the parent PN sequence generators. In addition, 2^m-1 unique Gold codes can be created from two parent PN m -sequences.

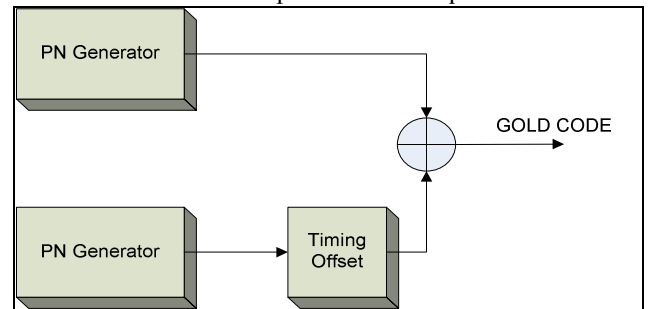


Figure 1: Gold Code Generation

The cross-correlation between any two Gold codes will yield either $-t(m)$, -1 , or $t(m) - 2$, where $t(m)$ is defined as follows:

$$t(m) = \begin{cases} 1 + 2^{\frac{m+1}{2}}, & m \text{ odd} \\ 1 + 2^{\frac{m+2}{2}}, & m \text{ even} \end{cases}$$

From this result, it was realized that gold codes, with correlation result of -1 , could be modified in order to make them orthogonal. The Gold Codes are padded with '0' such that the cross correlation result is zero. More interestingly, all the padded gold sequences are orthogonal to each other, resulting in 2^m-1 orthogonal gold codes, provided that all 2^m-1 orthogonal gold codes are parented from the same pair of PN m -sequences.

The concept of smart codes as introduced in [12], is a code sequence in which the auto-correlation yields a value of 1; and yields a value of 0 when shifted. Another property of a Smart Code sequence is the cross correlation with another smart code yields a zero for all τ where $\tau \leq \tau_c$ and τ_c is the

cross-correlation window that yields a zero value.

Smart codes can be complementary orthogonal codes that consist of two sets of codes C and S . The smart code sequence has a length of L chips and the code components C and S have code length $L/2$ chips. The result of the correlation between C and S yields a value of 1 when the codes are perfectly aligned (i.e. $\tau = 0$). When the codes are not aligned in time (i.e. $\tau \neq 0$) then the correlation between the codes is 0.

The number of smart codes that can be used in a system is limited. As a consequence, smart codes are not suitable for a multi-user access system but instead smart codes make an ideal candidate for code division duplexing systems.

The disadvantage to smart codes is that there exists very few of them, and they cannot be used for channelization. It also means that they are not suitable for cell and sector planning schemes.

V. CODE DIVISION DUPLEXING

Code division duplexing (CDD), proposed in [11] is an access mechanism that differentiates data transmission direction. Like frequency division duplexing (FDD) and time division duplexing (TDD) where transmissions can be separated into uplink and downlink channels on different frequencies in the case of FDD and different time slots in the case of TDD; information can be separated by spreading codes.

In [4], CDD was first proposed to be used as a means of enabling an ad-hoc overlay on a CDMA network with infrastructure support. The design of this project's CDD system is based on the design of the CDD system found in [4]. Particular to this design, transmissions are separated into three unique directions as shown in Table 1.

Mobile to base station, base to mobile station and mobile to mobile station transmissions each use a unique spreading code that identifies the direction. In other words, this CDD facilitates (on the physical layer) direct mobile-to-mobile communication along with the standard mobile-to-base station network topology used in cellular networks.

Table 1: CDD Duplexing Directions

Direction	Code Designation
Mobile Station to Base Station	Code 1
Base Station to Mobile Station	Code 2
Mobile Station to Mobile Station	Code 3

VI. PERFORMANCE OF CDD

Unlike the conventional DS-SS system where each individual user has their own code, in CDD CDMA, each user will have a code as well as a code that is shared. This shared code is the duplexing direction code. For instance, if there are multiple peer-to-peer sessions going on simultaneously then there will be MS units that will be using the same CDD code. Because of this, the multiple access interference is greater than a standard direct sequence spread spectrum (DSSS) system, as seen in figure 2.

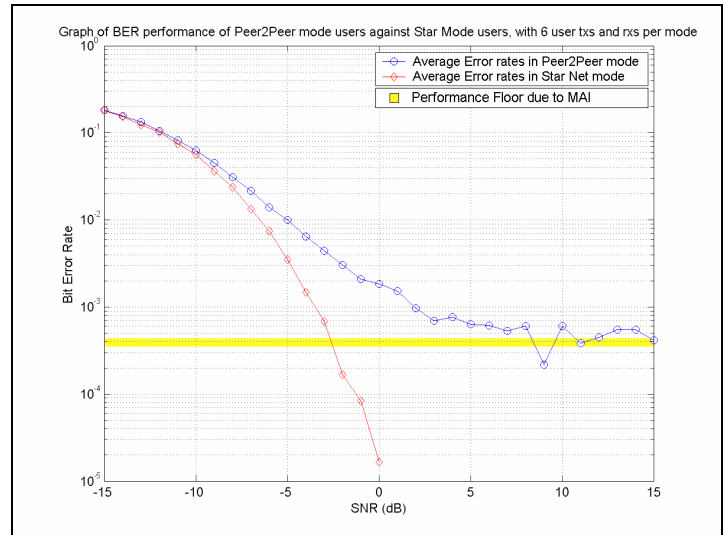


Figure 2: BER performance of 6 CDD users against 6 standard users with code length 128

VII. MULTIPLE ACCESS INTERFERENCE REDUCTION SCHEME FOR CDD

Due to the limitation of sharing codes for CDD, Code Assignment scheme is proposed to reduce multiple access interference in the system.

Table 2: Code Assignment in CDD

Direction	Code Designation	Code Length = 32	Code Length = 64
MS to BS	Code Set 1	12 codes	24 codes
BS to MS	Code Set 2	10 codes	20 codes
MS to MS	Code Set 3	10 codes	20 codes

Instead of merely assign one code to a duplexing direction, a set of codes can be assigned to a direction as suggested in table 2. This way the number of codes that are shared reduces because users executing the same direction transmission will be assigned different codes. Code assignment is facilitated by means of being centrally administered from the network. Codes are assigned during the call setup procedure. Seeing that the call setup procedure depends on communication with the base station, codes can be marked and allocated, thus avoiding reuse. However, as the system become loaded, reuse of a CDD code in a code set becomes more likely. However, reuse will not significantly affect the systems performance as shown in the section. It has been shown that the upper bound bit error performance is the same as the bit error performance in direct sequence spread spectrum.

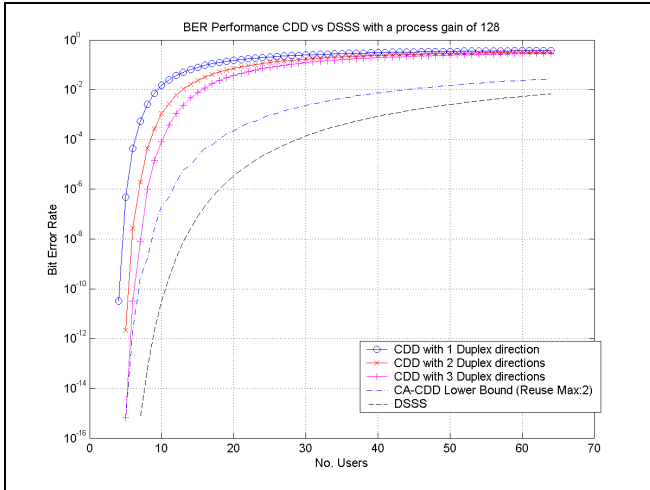


Figure 3: BER of CDD vs. DSSS

VIII. PHYSICAL LAYER DESIGN

Orthogonal Gold codes are used for code division duplexing, despite what was highlighted in [12] that to realize a CDD system, smart codes should be used. Orthogonal Gold codes are easily generated, and hence, very simple to implement in hardware; they have the properties of a pseudo random noise sequence, in that transmission energy is evenly spread across a bandwidth during spreading; they can be created from PN m-sequences with excellent cross correlation values; and are used in synchronization. Unlike smart codes that have a small subset of codes, orthogonal gold codes can be used in cell planning PN assignments. Thus each cell can be assigned its own set of Orthogonal gold codes used for duplexing.

In both receiver and transmitter structures, spreading and dispreading of data streams is accomplished with the orthogonal gold codes and channelization is accomplished with Walsh codes.

In the transmitter structure of the mobile station, the spreading of the data signal is however dependant on the control information sent down from higher layers of the protocol stack (see Figure 4). When the CDD code is determined, it is used to spread the data stream along with an orthogonal Walsh code that uniquely identifies the MS as shown in Figure 4.

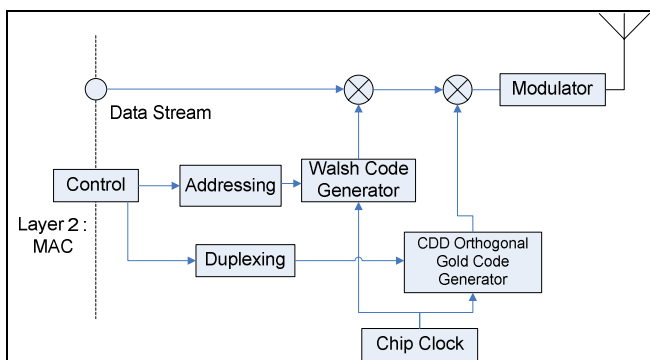


Figure 4: MS Transmitter Structure

In the transmitter structure of the base station, there is no intervention from the higher layers in the protocol stack. As shown in the Figure 5, the base station spreads all the incoming data streams, from 1 to k users, with the same

orthogonal gold code. This is done because the base station only transmits to mobile stations.

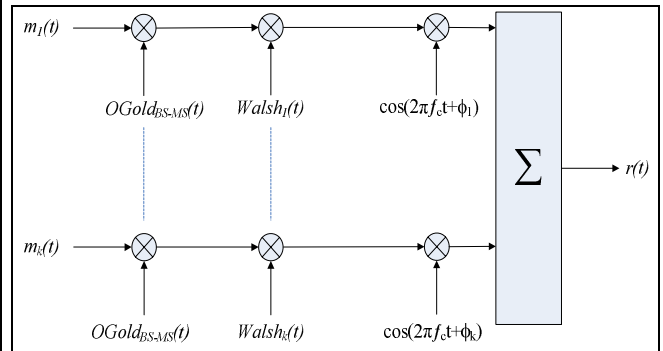


Figure 5: Base station transmitter structure

The MS receiver structure, like the transmitter structure, is given information from the control plane to allow it to be ready for switching between the peer-to-peer mode and the standard communication mode (MS-BS). As shown in Figure 6, the receiver structure resembles the transmitter structure.

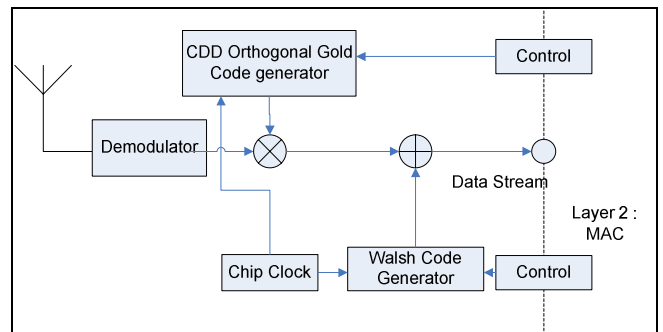


Figure 6: MS receiver structure

IX. MEDIUM ACCESS CONTROL

As can be seen in Figure 7, it is necessary to randomly access a radio channel for the call setup procedure is to be initiated. A TDD medium access protocol is proposed, based on Packet Reservation Multiple Access (PRMA) proposed in [14]. PRMA is used as the Medium Access Control protocol (MAC) because it is based on TDMA and slotted ALOHA, thus making it ideal as a TDD MAC protocol.

Beyond acquiring a channel to make channel requests, MAC is then centrally administered from the network.

The frame structure of the MAC protocol is based on the 3GPP specification for TDD mode transmission frame structure, in which, there are 16 time slots available in a frame; and a frame is 10 milliseconds in length and each time slot is 625 μ s long.

Of the sixteen time slots there is 1 time slot always reserved for either the uplink or downlink. This ensures that important control information can always be transmitted even if the application is downstream or upstream based.

X. PEER-TO-PEER CALL SETUP

The handshaking protocol for the system, during a MS to MS call, is based on the call setup used in GSM (which is in

turn based on the call set up in Q.931). Every MS attempting to instantiate a call must communicate with the base station.

1. The mobile device must access a random channel in order to send a request for a traffic channel that has been assigned by the network. The method by which a traffic channel is assigned shows the traits of a centralised networking topology. However, one of the main purposes behind doing this is to ensure that the mobile device can not communicate without the permission of the network.

2. The network then assigns a channel to the originating mobile. The network will assign a code such that code sharing is minimised.

3. The initiating mobile then notifies the network of the type of service it is requesting; in this case it sends a voice service request.

4. Like in GSM, all the security features of the impending call are negotiated with the mobile device making the call and the network before the call setup is complete. Therefore the mobile send a security setup request.

5. The network will then respond with security information that includes the cipher to be used and the cipher mode.

6. The originating mobile then sends a call setup request that contains the details of the target mobile.

7. The network will respond to the mobile with information that confirms that the network is prepared for the call, that the number being dialled is in fact a mobile device and also information of the cell location of the target mobile.

8. The MS initiating the call will send out a search request known as a ping to commence the hand shaking procedure with the target MS. The ping contains the address of the originating MS, the address if the target MS and a session ID. The ping is sent for two reasons. The first reason being that there could be a possibility that the target MS has moved out of cell coverage range but is still within the transmitting vicinity of the MS making the call. The second reason is that, there is no guarantee that even if the target MS is in the same cell, that it means that the MS is in the transmission vicinity of the MS originating the call. At this stage, the target MS has not yet received any forms of transmission. When the network returned the possible whereabouts of the target MS to the originating MS, this was merely a query of the HLR database.

9. If the target MS receives the ping, which is sent on a known broadcast channel.

10. The target MS will begin the procedure to make a peer-to-peer connection using the orthogonal gold code assigned by the network. The target MS will notify the network (using the information found in the ping) that it has received a ping and the network will assign a channel to the target MS.

11. The target MS will then send an acknowledge response to the ping (know as a pong) on the channel that has been assigned to both devices. Like the ping, the pong contains the session ID but, unlike the ping, the pong contains the status of the target MS, which could indicate the device is busy or available.

12. Provided that the target MS is available, a peer-to-peer

connection will be setup.

However, there stands the chance that the target mobile is not in signal range of the ping. As a consequence the network continues the process of instantiating the call connection. For the network to continue to do this, the originating MS has to report a ping timeout error back to the network. The network, which still has the session information that was requested from the home location register (HLR), can now check the status of the target MS. If the target MS is available, the network will continue the usual call setup protocol, and instantiate the voice mode call through the network.

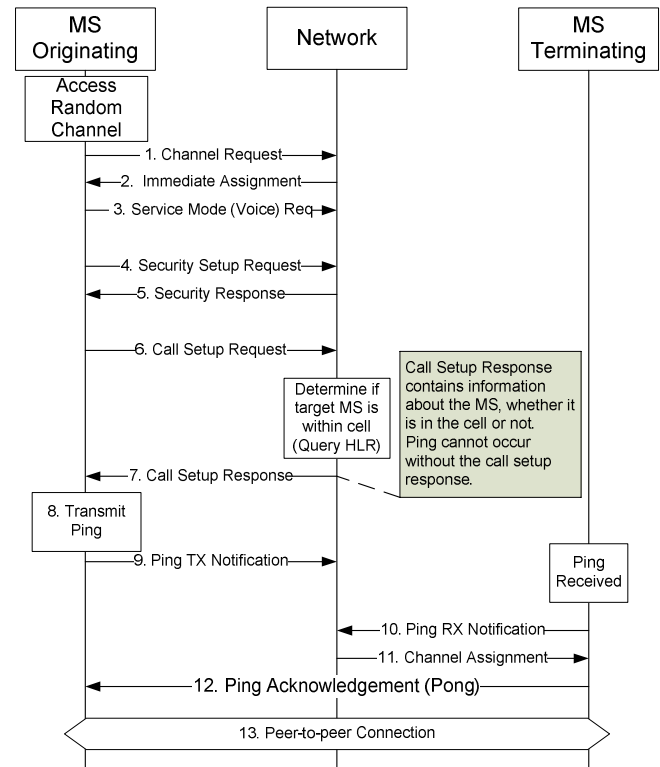


Figure 7: Call setup procedure (MS-MS)

XI. SIMULATION SETUP

In order to verify the design of the CDD/TDD CDMA mobile system, a simulated environment is needed to assess the system's performance.

The simulation represents the ad-hoc network overlay on a fixed cellular CDD/TDD CDMA system. In the simulation, nodes use traffic generating stochastic processes to load the network. Each node transmits data via BPSK into the air represented by the channel model. The channel model will consist of a range of operating environments. The performance of the system will be examined in dense urban, urban, sub-urban and rural environments. Using these channel models, outage boundaries can be determined.

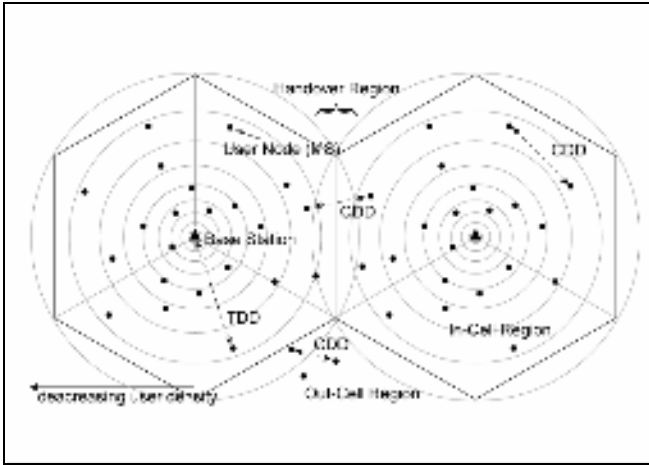


Figure 8: Graphical representation of model

A typical cell model consists of a BS node and a number of MS nodes, where the BS node is essentially a special MS node with high capacity and no mobility.

Each node will be randomly distributed in a confined area which represents the nodes' current cell. A cell consists of concentric portions that have decreasing user density (nodal density) from the centre of the cell outwards, as shown in Figure 8. Each node possesses a number of parameters which include position (x,y) , velocity (v) , path loss (pl) , carrier to interference ratio (CIR) and signal to noise ratio (SNR) .

The setup will compare and contrast the networking topologies, one being the standard cellular infrastructure setup (star network topology) and the other being the hybrid setup that consists of the ad-hoc overlay on the standard cellular infrastructure.

The key resulting parameters are the overall system capacity from the two topologies in terms of user loads; capacity in out-cell regions; and coverage range improvements.

XII. CONCLUSION

The CDD/TDD-CDMA system facilitates MS-MS communication on the physical layer, as well as the BS-MS communication. This results in the overlaying of an ad-hoc like architecture on the standard cellular infrastructure. The advantage of separating transmission direction using the code division duplexing is that unwanted transmission can be rejected (and thus ignored) by the receiver.

It has been shown that code sharing in CDD increases the signal to interference ratio. Code assignment was recommended to combat this problem.

The MS and BS transmitter/receiver structure of such a network is considered as well as the use of Orthogonal Gold codes as the coding format used to provide the code level differentiation. In addition, a handshaking protocol is proposed that facilitates the integration of MS-MS communications into the standard network infrastructure.

The proposed system architecture offers the following benefits: simple frequency reuse planning for network operators and radio spectrum regulator bodies; simple power control; increase in system capacity because of the inherent advantages of a hybrid topology; conservation of power by

mobile devices; and an increase in coverage.

Along with the abovementioned advantages, the primary focus of the design is to accommodate the sparse user density environments through the cost lowering attributes of the design.

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