Co-Channel Interference Management in Next Generation Broadband Wireless Networks

Subir Varma, Ph.D .
Vice President, Network Technology
Aperto Networks
1637 South Main Street
Milpitas, CA 95035
(408) 719 9977
email: svarma@apertonet.com

1.0 Introduction

The current generation of Broadband Fixed Wireless Equipment is typically deployed in a single large cell configuration, also known as a megacell or supercell. This architecture does not scale very well and quickly runs out of capacity as the number of subscribers increases. The Next Generation of Wireless Network equipment is architected so that it can be deployed in a multi-cell fashion. The sizes of the cells are smaller compared to a megacell, and at the same time spectrum can be re-used between cells. These characteristics give the architecture scalability, and make Broadband Fixed Wireless comparable to the cost/capacity range of Cable Modem and DSL technologies for mass volume deployments.

There are several technical challenges that have to be overcome in order to make multi-cell deployments possible. One of the most important issues is operation in the presence of co-channel interference. Most discussion on the subject of Next Generation Wireless Networks deals with the topic of Non-Line of Sight operation and how to overcome large multi-path delay spreads, thus overlooking the problem of co-channel interference. The objective of this paper is discuss co-channel interference management in more detail and point out various techniques by which interference can be reduced. One of the characteristics of co-channel interference management is that it requires co-ordination across multiple layers of the protocol stack, so that architectures that over-emphasize a single layer of the protocol stack are not able to manage interference effectively.

We discuss both intra-cell as well as inter-cell co-channel interference management. Intra-cell co-channel interference is caused due to re-use of frequencies within a cell, while inter-cell co-channel interference is caused due to re-use of frequencies between cells. We discuss how the co-channel interference scenario is different for fixed wireless networks as opposed to mobile wireless networks. The differences between Frequency Division Duplex (FDD) and Time Division Duplex (TDD) architectures on co-channel interference is pointed out.

Co-channel interference management techniques are broadly classified into two categories, namely interference reduction and interference mitigation. Interference reduction techniques seek to reduce the amount of co-channel interference, while interference mitigation techniques seek to recover from errors caused due to co-channel interference. The combination of both of these techniques constitutes an extremely powerful tool in the quest for next generation scalable broadband wireless access technology.

2.0 What is Co-Channel Interference?

Co-channel interference is caused due to simultaneous transmissions on a common frequency channel by two or more transmitters in the vicinity of each other, such that their signal strengths are high enough to cause errors in the received data. The reason why several transmitters use the same frequency, is in order to increase system capacity through frequency re-use. Frequency spectrum is a scarce resource, and in any given area, an operator has access to only a limited amount of spectrum. The operator's objective is to provide blanket coverage in his chosen market using his available spectrum. He attempts to do so by re-using frequency in the following ways:

- Re-use of frequencies within a cell
- Re-use of frequencies between cells

An unfortunate side effect of frequency re-use is co-channel interference.

Without frequency re-use, system capacity is **spectrum limited**, i.e., the system runs out of capacity when it runs out of additional spectrum which it can use. In a well designed system using frequency re-use, the system capacity is no longer spectrum limited. However there an upper limit to the extent to which the system capacity can be increased by re-using a limited amount of frequency, and this limit is reached at the point where the system becomes **interference limited**, i.e., a further increase of frequency re-use beyond the limit will cause the system capacity to decrease due to excessive interference. An objective of the system architecture is to maximize the interference limited capacity of a system. In this paper, we will point out several design principals and guidelines that should be followed in order to achieve this objective.

On a historical note, frequency re-use is now integral to the operation of cellular voice networks, which have well understood rules on how to do so. However, just like the very first wireless voice system, the first generation of broadband wireless networks were designed without paying too much attention to the question of frequency re-use (due to the fact that they were derived from off the shelf cable modem technology). As a result they are quickly running out of capacity. However the next generation of broadband wireless networks have been designed from ground up for wireless environments, and they incorporate several techniques to increase frequency re-use by handling co-channel interference.

3.0 Occurrence of Co-Channel Interference

Co-channel interference occurs under a variety of circumstances, in several different environments. In every case, the factors that govern the severity of co-channel interference are different, and sometimes people make the mistake of interpolating from one case to the other, without examining all the underlying factors. In this section, our objective is to examine the factors that influence co-channel interference for a couple of important scenarios: Mobile vs Fixed and FDD vs TDD.

3.1 Co-Channel Interference in Mobile vs Fixed Wireless

Co-channel interference in mobile wireless differs from that in fixed wireless, in the following ways:

- *Omni directional vs directional antennae*: Remote units in mobile systems use omni-directional antennae since their mobility makes it impossible to keep a directional antenna properly oriented. Remote units in fixed wireless systems do not have this problem, as a result they are able to use directional antennae that not only boost the signal strength in both directions, but also reject all radiation except that in a narrow beam in the direction of the base station. Mobile units on the other hand receive signals from all directions, thus significantly increasing the amount of co-channel interference that they have to combat.
- *Circuit switched voice vs packet switched data traffic*: The nature of traffic carried in mobile systems is very different from that carried in fixed wireless systems. Mobile systems pre-dominantly carry circuit switched voice traffic, while fixed wireless systems carry packet switched data traffic. Voice flows tend to have longer duration and are less bursty as compared to data traffic, as a result the type of interference generated by voice is very different than that generated by data. Reflecting the nature of the traffic, interference generated by data traffic also tends to be bursty.
  Another factor that influences the ability of these systems to handle co-channel interference, is the differing reaction to channel errors for voice as compared to data traffic. Voice traffic can tolerate a higher degree of packet errors on the wireless link, however it cannot use re-transmissions of errored packets due to a tighter latency constraint. Data traffic in fixed wireless systems on the other hand has a more stringent packet error rate requirement, but it can use packet re-transmissions to recover from channel errors.
  As described later, these differences between circuit switched voice and packet switched data traffic can be exploited by fixed wireless systems in using new kinds of interference avoidance schemes that are very effective in overcoming bursty interference.
- *Interference environment*: The co-channel interference environment in mobile systems is very dynamic as the remote unit travels from one place to another, and is subject to new sources of interference, or moves away from existing sources of interference. The co-channel interference environment in fixed wireless systems on the other hand tends to be quasi-static and changes at a much lower rate. In most cases, the dominant interferer in fixed wireless system tends to be the same

over time, hence there is a class of interference reduction techniques that have been designed to exploit this particular characteristic.

As a result of these factors, fixed wireless systems have more effective means to deal with co-channel interference, as compared to mobile systems. In practical terms, this translates into a higher degree of frequency re-use, and thus higher spectral efficiency for fixed systems.

3.2 Co-Channel Interference in FDD vs TDD Environments

The previous generation of wireless communication systems were based on analog technology, which necessitated that transmission and reception happen on distinct channels, i.e., in the Frequency Division Duplex or FDD mode. The advent of digital technology has made possible a new mode called Time Division Duplex (TDD), in which both transmission and reception happen on the same channel, but a different times. The TDD mode of operation holds some tremendous advantages for wireless systems, created due to the reciprocal nature of channel characteristics in the two directions which enables the implementation of several link control schemes that have no counterparts in the FDD domain. TDD also enables flexible allocation of up and down bandwidth, which has several benefits in the traffic engineering area.

FDD and TDD systems differ in their handling of co-channel interference in the following ways:

- *Intra-cell Co-channel Interference*: Consider a four sector cell, in which sectors 1 and 3 use the same channels, as do sectors 2 and 4. When CPE1 transmits upstream in sector 1 of a FDD system, it does not interfere with CPE2 in sector 3, which is the sector opposite to its own. On the other hand, in a TDD system such an interference scenario can potentially occur, if CPE1 is transmitting at the same time that CPE2 is receiving. However such a situation can be easily avoided by synchronizing the upstream and downstream transmissions for all sectors in a cell that share the same frequency. Such a synchronization requirement is easy to fulfill, since all channels originate from one or more co-located base station controllers. Note that by synchronizing the upstream and downstream transmissions, the system loses some of the flexibility that TDD has in dynamically adapting its up/down BW ratio. However, such adjustments can still be carried out across the aggregate traffic going to all ports sharing the same channel in the cell.
- *Inter-cell Co-channel Interference*: Inter-cell co-channel interference scenarios for FDD and TDD systems are shown in Figures 1a and 1b respectively. These figures consider the case of intra-cell frequency reuse of two and an inter-cell frequency reuse of one. As indicated by the arrows in Figure 1a, a target base station in the FDD system receives interference from CPEs from other cells, while a target CPE receives interference from base stations in other cells. Figure 1b shows that target base stations and CPEs in TDD systems receive interference from both base stations and CPEs in other cells. A way to remove the base station to base station or the CPE to CPE interference in TDD systems is by

synchronizing the TDD frames in adjacent cells. However this option is not desirable from the cost/complexity or upstream/downstream BW flexibility points of view, and it also does nothing to reduce the CPE to base station or base station to CPE interference, that also plagues FDD systems. Fortunately there exist a host of other options that can be used to reduce interference, that make inter-cell synchronization un-necessary. These techniques will be discussed in detail in the next few sections, and towards the end of the paper we will re-visit the topic of TDD inter-cell interference, and how it can be reduced.

4.0 Combating Co-Channel Interference

A variety of powerful tools are available in the designer's arsenal to combat the effects of co-channel interference. The objective of this section is to provide brief descriptions of several of these techniques, which have been broadly classified into two categories:

- *Interference Reduction Techniques*: These techniques seek to reduce the amount of co-channel interference inflicted by a base station or CPE on neighboring cells or sectors. Most of these techniques work through algorithms implemented at the transmitting end of the link.
- *Interference Mitigation Techniques*: These techniques seek to recover from the effects co-channel interference in case the interference reduction techniques have not been effective enough. Most but not all of these techniques work through algorithms implemented at the receiving end of the link. Interference mitigation comes at a cost, usually of link bandwidth, but enables the system the keep functioning, albeit at a lower level of efficiency.

4.1 Interference Reduction Techniques

4.1.1 Power Control

When transmissions occurs between the base station and a CPE (or vice versa), then the resulting power from that signal leaks into neighboring cells and sectors and is directly responsible for all occurrences of co-channel interference. From this observation, it is obvious that transmit power control plays an integral role in interference reduction techniques. In order to reduce the amount of signal going into neighboring cells, the most straightforward policy is to transmit with lower power. However this conflicts with the requirement that in order to receive a signal reliably, the SINR (Signal to Noise + Interference Ratio), defined by

SINR = Received Signal Power/(Noise Power + Interference Power),

needs to be greater than a well defined threshold. Hence the optimal policy is to transmit with just enough power so that the SINR at the receiver is maintained above the threshold. This optimal transmit power is then a function of the link attenuation between the transmitter and the receiver, and also the Interference Power at the receiver. The Link Attenuation in a fixed wireless system changes relatively slowly, if at all. However the Interference Power is a more dynamic quantity and varies in a stochastic manner, depending upon the current transmission environment.

There is a fairly large amount of literature [1], [2], that has been written on the topic of distributed power control, and the policies that should be pursued in order to converge to the correct SINR level. Unfortunately these papers were written in the context of cellular voice systems, and make several assumptions that are no longer valid in the broadband data context, such as (a) Steady interference power level, rather than a stochastically varying one, (b) Exact knowledge of the SINR value, (c) Continuous monitoring and adjustments of power levels etc. Some of the recent products in the broadband fixed wireless space have incorporated new and sophisticated power control algorithms that do not make these assumptions, and are consequently able to solve the problem of optimal transmission power management.

There is an interesting interaction between transmit power control and interference level that is worth mentioning here. When the SINR level at a node drops below the threshold, then the power control algorithm reacts by boosting the transmit power. However doing so causes the interference level in the neighboring cells and sectors to go up, and nodes located there react by increasing their own transmit power level, which causes even more interference in the target sector,…,ad. Infinitum. This behavior, which soon causes every node to be transmitting at its maximum power level, has been called the "Party Effect". If it causes the steady state value of the SINR to be above the threshold, then communication can continue. However, if it is below the threshold, then the system can still function if it can adaptively change it's modulation level and thus reduce the SINR threshold required for reliable communication (further discussion of adaptive modulation is in Section 4.2.2).

TDD systems hold some unique advantages in the power control area. In contrast to FDD systems whose downstream transmitter is always in the ON state, in TDD systems transmissions are made strictly in response to the availability of data to transmit, and at other times the transmitter is turned off. This helps in reducing the amount of power radiated, and thus co-channel interference. Also TDD systems enable the transmit power of each burst to be controlled individually in both directions in contrast to FDD in which the continuous downstream transmission is done with maximum power. Consequently a TDD base station uses maximum power only when transmitting to CPEs located at the edge of the cell, and uses lower power for nearby CPEs.

4.1.2 Polarization Diversity

The base station or CPE antennae can be configured to transmit or receive using either horizontal or vertical polarization. Polarization can be used as a tool to reduce co-channel interference due to a property of polarized transmissions known as Cross Polarization Discrimination or XPD. Due to XPD, when a horizontally polarized antenna receives a co-channel signal sent from a vertically polarized antenna (and vice versa), the effective signal strength is reduced by several dB. The amount of XPD is reduced if the signal undergoes extensive multi-path reflections.

Figure 2 has an example that shows static polarity assignment leads to reduced co-channel interference for the case of TDD systems. This example considers the case in which 2 channels are used to provide blanket coverage, with 4 sectors per cell, an intra-cell re-use factor of 2 and an inter-cell re-use factor of one. Figure 1b had illustrated the frequency assignments without the use of polarization diversity for TDD. Let R be the radius of the cell and let x be the distance between a target receiver and its co-channel interferer. As can be seen in Figure 1b, (x/R) = 2 which leads to a SINR requirement of 7.5 dB. This SINR is not sufficient to support even the lower modulation levels. Figure 2 illustrates the frequency assignments with the use of polarization diversity, such that all cells in a row use the same polarization value. Going through the same analysis as before, (x/R) = 4 for this case, which leads to a SINR requirement of 15 dB, which is sufficient to support QPSK modulation type (these computations use a propagation exponent of 2.5, which is appropriate for suburban and urban deployments).
Dynamic polarity assignment is appropriate for Non-Line of Sight (NLOS) cases, in which the XPD is reduced due to multiple reflections. In this case it is not feasible to statically assign polarity values to cells and sectors as described above. However it is possible for each receiver-transmitter pair in the system to dynamically choose the polarity that leads to lower SINR. Such a scheme will work as follows: The transmit and receive polarities at the base stations and CPEs are not fixed, but are chosen dynamically as a function of the combination that leads to the lowest SINR. This requires that the base station be able to change its transmit and receive polarity from burst to burst, depending upon the CPE from which the burst is coming from or going to.

4.1.3 MAC Level Transmission Control

The objective of MAC level transmission control schemes is to reduce co-channel interference by appropriately scheduling packet transmissions. Such schemes work best with burst mode transmissions in both directions, so that the scheduler has complete control on when it chooses to transmit. MAC level transmission control schemes have been suggested to handle both inter-cell as well as intra-cell co-channel interference, and we will discuss them briefly below:

- *Inter-Cell Interference Reduction*: Chawla et.al [3], [4], have suggested a couple of schemes to reduce inter-cell interference through MAC scheduling. The first scheme is called Time Slot Re-use Partitioning (TSRP) and works by synchronizing the frames and transmission slots in neighboring cells, and then assigning those slots to individual cells to use, i.e., the other cells are not allowed to transmit at those times. This obviously has the effect of reducing the co-channel interference by reducing the number of simultaneous transmissions in neighboring cells. Their second scheme is called Dynamic Resource Allocation with Interference Avoidance (DRA-IA). The basic idea of DRA-IA is for every base station to periodically "turn-off" each of its beams for a certain amount of time. The periodic turn-off introduces a predictable non-uniformity in a terminal's performance, and therefore permits each terminal to identify a preferred time period for transmission. A drawback of both these schemes is that it requires time and frame synchronization in neighboring cells, in addition to exchange of control information, which complicates system design.

- *Intra-Cell Interference Reduction*: There are several references that propose to reduce intra-cell co-channel interference through MAC scheduling [5], [6]. As in the inter-cell case, all these proposals require that frame and transmission slots be synchronized across multiple sectors in a cell. This requirement is more plausible for the intra-cell situation, since all the equipment is located at one place in the base station. Fong et. Al. [5] propose a method called Staggered Resource Allocation (SRA) to reduce intra-cell co-channel interference. SRA works by dividing the full frame into a number of sections that are equal to the number of sectors in a cell. Each sector is then assigned a prioritized list of sections that it can use, such that it tries to use the higher priority sections first. The section priorities are assigned in a manner such that the highest priority corresponds to simultaneous transmissions on opposite sectors, while the lowest priority is assigned to simultaneous transmissions on neighboring sectors. Leung and Srivastava [6] later extended the SRA technique by borrowing some ideas from TSRP. There is another set of published work that applies techniques from Graph Theory to this problem [7], [8]. These algorithms work by identifying the collection of each set of nodes that can transmit simultaneously while maintaining good SINR at the receiver. Given this information, the scheduler can then make intelligent choices about transmissions that optimize performance measures such as throughput. This problem has some similarities to the Head of Line Blocking problem encountered in input queued switching fabrics.

4.1.4 Smart Antenna Technology: Adaptive Beam Forming

Adaptive beam forming techniques work by being able to direct the transmit signal from the base station towards individual CPEs. This reduces the amount of signal that is radiated towards other parts of the cell, and thus the interference power. This technology effectively replaces the point to multi-point downstream channel with a point to point link. This property of Beam Forming systems also points to a potential problem, since all existing MAC layer technology for broadband wireless systems relies on a broadcast downstream channel on which the base station can send system control messages. The absence of the broadcast channel leads to the requirement of a different type of MAC than those prevalent today.

4.1.5 Cell Frequency Planning

Cell frequency planning is one of the oldest tools in the system designer's arsenal to combat co-channel interference, and one that is used exclusively by the current generation of TDMA based cellular voice networks. The basic idea is to avoid using the same channels in neighboring cells, and leave sufficient distance between such cells, such that the resulting the SINR is below the threshold required for reliable reception. Systems using cell frequency planning reach their capacity as a result of spectrum exhaustion rather than excessive interference. The main problem with this technique is reduction in system capacity, since only a fraction of the total spectrum is available in each cell. However it remains as a viable tool to handle co-channel interference, and if everything else fails, then the planner can always use it as a last resort.

4.2 Interference Mitigation Techniques

4.2.1 ARQ – Re-Transmissions

Automatic Repeat request or ARQ is a re-transmission protocol that can be implemented at the link layer of a wireless system in order to recover from packet errors. When a packet is lost due to co-channel interference, then the receiver sends a NACK back to the transmitter. In response, the transmitter then attempts to re-transmit the errored packet at a later time. The following questions arise – Is ARQ an appropriate way to combat co-channel interference, and if so what are the conditions under which it is most effective?

ARQ can be a very effective way to combat co-channel interference, for the following reasons: Several investigators have made the observation that the interference process at a receiver does not exhibit a long term variability, but instead is characterized by sudden spikes and short term behavior. Moreover, every receiver is subject to one transmitter that is its dominant source of interference [4]. These properties imply that co-channel interference is a highly stochastic process, co-channel interference will occur only if transmissions to the target receiver overlap with those from the dominant interferer. If all transmissions in the system are in the burst mode, i.e., they are carried out strictly in response to availability of data, then such an overlap would happen relatively infrequently. If this is the case, the ARQ is an excellent way to recover from the resulting error, since there is only a small probability that the re-transmissions will also overlap in time. This explanation also points out the conditions under which ARQ would effective, i.e., for burst transmissions. When transmissions are in the continuous mode, as in the downstream direction for FDD systems, then ARQ is less effective, since the source of interference is constant over time. ARQ is most effective to recover from low to moderate error rates. When the interference is strong enough to cause high error rates, then the use of ARQ alone can cause a severe decrease in the available bandwidth. In such cases the system should couple ARQ with other techniques such as Adaptive Modulation to effectively combat interference.

One of the early proposals to use ARQ against co-channel interference was a protocol called Capture Division Packet Access (CDPA) [9]. This was a simple protocol, which used a inter-cell frequency re-use factor of one, and recovered from the resulting interference by using Stop and Go ARQ. This protocol worked well at moderate traffic rates, but at higher rates the interference caused the net throughput (or goodput) to fall steeply (similar to the behavior of the Aloha protocol). We will show in the next section how this situation can be avoided by using adaptive modulation.

4.2.2 Adaptive Modulation/FEC Control

Adaptive Modulation is defined as the ability of a base station to choose the right level of modulation, for all transmissions to or from a CPE. By using this feature, the base station is able to simultaneously support a set of CPEs, each of which may have a different modulation. Since different modulation types have different SINR thresholds, adaptive modulation can be put to use in several different situations. The most common use, is in the context of increasing the cell coverage, so that hard to reach CPE locations with excessive link attenuation can be served using lower order modulation. In addition, adaptive modulation can also serve as a very useful tool against co-channel interference, as illustrated in the following examples:

- In the section on power control, we pointed out that there are cases when the power control algorithm leads to the "party effect", during which every node is transmitting at maximum power in response to excess interference from neighboring nodes. The SINR values that are achieved at the various nodes in such situations are not subject to further control, and in absence of adaptive modulation, a node whose SINR is below the threshold will not be able to function. With adaptive modulation on the other hand, such a node can choose a modulation level that is best suited to its SINR, and thus continue to function.
- As pointed out in the previous section, the use of ARQ to combat co-channel interference breaks down when the packet error rates exceed a certain threshold. In these situation the system should reduce the modulation level to that CPE, which has the effect of decreasing the SINR threshold required for good reception, and thus restoring good link conditions.

Adaptive modulation should be able to adapt in both directions, so that if the co-channel interference goes down and the link quality improves, then the modulation level should be increased. Considerations related to adaptive modulation are independent of the fact whether the system employs Single Carrier modulation or Multi-Carrier (OFDM) modulation. Even though we only discussed adaptive modulation in this section, note that the same techniques apply to the case of adaptive FEC as well.

4.2.3 Interfering Signal Cancellation

Interfering signal cancellation using multiple antenna arrays at the receiver is an emerging technique for co-channel interference reduction [10]. The basic idea behind this technique is the following: The signal at the output of each receiving antenna is a weighted linear combination of the desired signal and the interfering signals. If the number of antennae is at least as large as the number of interferers, then it is possible to recover the desired signal and cancel out the interferers by choosing the weights appropriately. Some issues related to the practical application of this technique include:

- Cost of supporting multiple antennae and de-modulator chains: This is usually prohibitive for the CPE side, but is more feasible for the base station.
- Channel estimation: The choice of optimal weights requires knowledge of the channel. Training sequences can be used for this purpose, but they consume channel bandwidth, and also require co-ordination between neighboring cells.

"Blind" methods for channel estimation have been proposed [11], but their performance is sensitive to the validity of the structural properties assumed.

4.2.5 Adaptive Channel Allocation

Adaptive channel allocation is a useful technique against co-channel interference, if more than one channel is available in each sector. Recalling the property that the number of dominant interferers does not exceed one or two per receiver, it follows that if the interfered node changes channels, then there is a good chance that the dominant interferer can be avoided. The decision to change channels can be made after other remedies, such as adaptive modulation or ARQ fail to work.

5.0 Inter-Cell Interference in TDD Systems Re-Visited

In Section 3.2 it was pointed out that there are more sources of inter-cell interference in TDD systems, as compared to FDD systems. We now show that by making use of the interference reduction techniques discussed in Section 4, it is possible to keep the interference level in TDD systems comparable or below the level in FDD systems, without having to synchronize neighboring cells.

We start with the TDD system shown in Figure 1b, with an inter-cell frequency re-use of one, and an intra-cell frequency re-use of two. As shown in this figure, the base station in a neighboring cell can interfere with the upstream transmissions to the base station in the target cell. This can lead to SINR = 7.5 dB, since the interferer is separated by a distance of 2R from the target base station. This is clearly un-acceptable, and in order to improve the performance we apply polarization discrimination, with alternating rows of cells using the same polarization, as shown in Figure 2. This causes the separation between the interfering base stations and the target base station to increase to 4R, which leads to SINR = 15 dB. This SINR level is acceptable for QPSK (whether single or multi-carrier) transmissions, but we now show that by using some other interference control tools, it is possible to use 16 QAM modulation most of the time. If the TDD system uses burst transmission mode in the downstream, then it can employ power control on a per CPE basis. This implies that the interfering base station will transmit at maximum power only when it transmits to the CPEs that are near the edge of its cell, otherwise it will use lower power thus reducing interference. Lets assume that the CPEs are distributed uniformly between the distances of zero to R in the interfering cell, then the average SINR = 22 dB at the target base station which is sufficient to support 16QAM modulation. The burst nature of the TDD system has thus replaced the deterministic interference scenario by a stochastic one. The amount of interference will go up in the following two random cases:

(a) The downstream frame in the interfering base station coincides with the upstream frame in the target base station. Since the two cells are not synchronized, this is a random event.
(b) The interfering base station is transmitting to a CPE at the edge of its cell.

When both these events coincide, the SINR required at the target base station decreases to 15 dB, which will cause packet errors if 16QAM is being used. Using ARQ, the target system should be able to recover from the errors after one or two re-transmissions most of the time. In the unlikely event that the CPEs in the interfering cell are mostly located near the edge of the cell, the interference will be strong enough to cause very frequent errors. In this case the target system can change its FEC or modulation type. If the interference has a diurnal pattern, then the system can still use 16QAM during times that the interference is lower.

In a FDD system with polarization diversity, the distance between the interfering base station and the target receivers is 5R, which leads to SINR = 17.5 dB. However note that since the downstream transmissions in FDD mode are sent in the continuous mode at peak transmit power, the level of interference remains constant over time. This precludes the use of interference reduction techniques such ARQ and adaptive modulation. From this comparison we can draw the following conclusions:

- Contrary to conventional wisdom, the inter-cell interference levels in well designed TDD systems is lower on the average as compared to FDD systems.
- Again contrary to conventional wisdom, the lack of synchronization between neighboring cells in a TDD system helps in improving performance by randomizing occurrences of co-channel interference, thus making possible the use of ARQ to recover from them.

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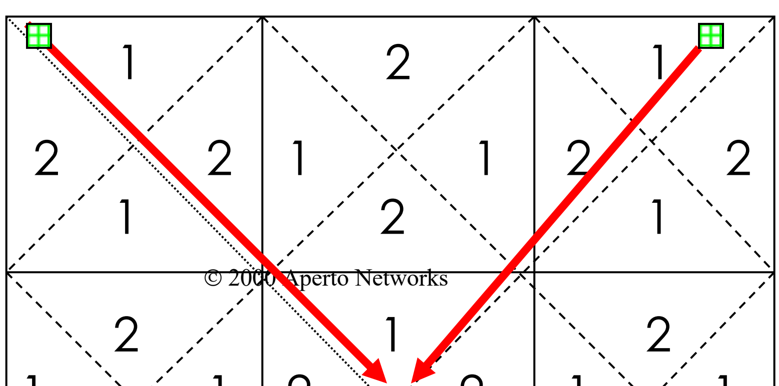
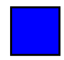


Fig 1a:
Interference
in a FDD
System



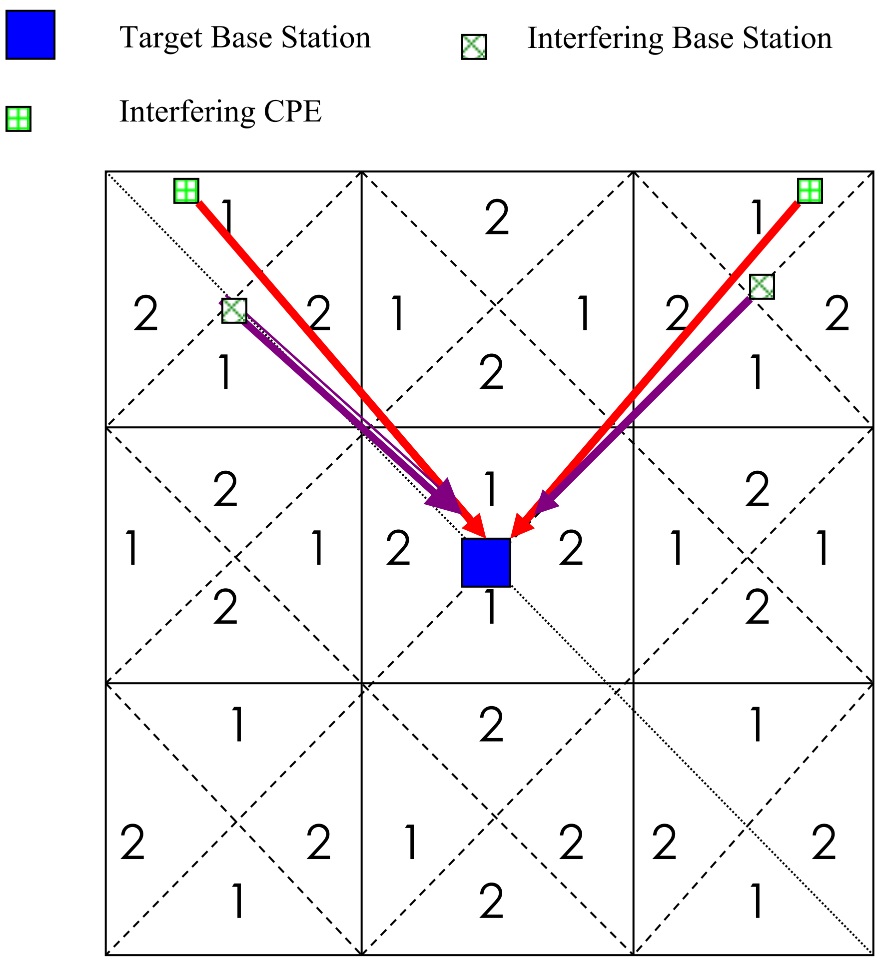
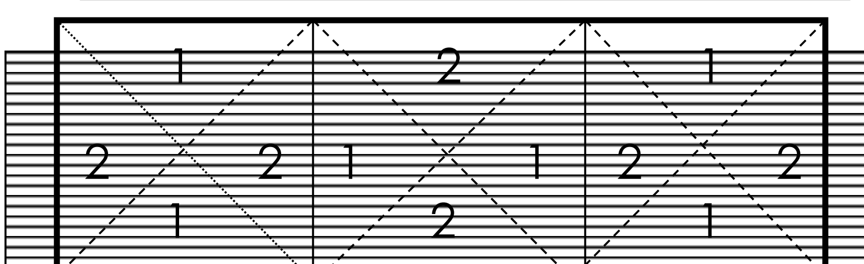


Figure 1b:
Interference
in a TDD
System

Horizontal
Polarization



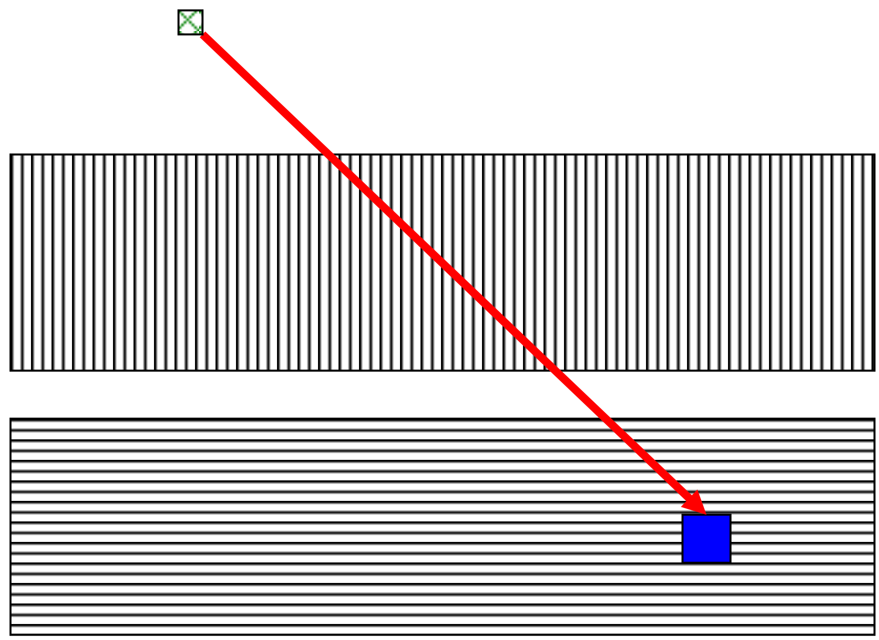


Figure 2: Use of Polarization to reduce interference

