Multiuser Capacity of Cellular Time-Varying Channels

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Abstract

The next generation of wireless networks will require efficient use of the underlying time-varying channel. Cellular architectures efficiently utilize the limited spectrum by reusing the same channel in spatially separated cells. However, frequency reuse introduces cochannel interference, which determines the data rate that can be supported by each channel for a given BER. The efficiency within a cell is quantified by its spectral efficiency: the data rate per user per unit of bandwidth. In this paper, the maximum spectral efficiency for cellular systems with channel estimation and transmitter feedback is derived from Shannon theory. We first review capacity results for single-user time-varying channels, which show that efficiency is maximized through a combination of power control, adaptive coding, and variable data rates. We then extend this result to the multiuser capacity region for both broadcast and multiaccess channels. This yields an analytical framework to compare the efficiency of channel sharing within a single cell using TDMA, FDMA, and CDMA. We conclude that CDMA with interference cancellation is optimal, but TDMA and FDMA have superior performance if interference cancellation is not exploited. Moreover, if the received power of all users is kept constant, then CDMA with interference cancellation does no better than FDMA and TDMA.

1 Introduction

Wireless communication systems require efficient use of the limited available spectrum and the underlying time-varying channel. Methods to divide the spectrum among many users include frequency-division, time-division, code-division, and hybrid combinations of these methods. Although there have been many performance comparisons of these techniques in the literature [1, 2, 3], these studies generally required some assumptions about the system specifications. In this work, we consider the multiuser capacity of a general time-varying channel, and compare these different spectrum-sharing techniques against this theoretical maximum for a single cell.

We will first describe previous results for the capacity of a single-user time-varying channel, when the channel variation is tracked by both the transmitter and receiver. In this case, the capacity is achieved by adapting three parameters to the channel variation: transmit power, data rate, and coding scheme. We then extend the single-user time-varying capacity analysis to multiuser channels. The rate regions for both broadcast and multiaccess channels, which correspond to the downlink and uplink, respectively, of cellular radio communications, are evaluated. We will see that CDMA (with interference cancellation and no power control) and FDMA techniques both achieve the maximum total rate for multiaccess channels, and CDMA achieves the maximum rate region for broadcast and multiaccess channels. In addition, if power control is used to equalize received power in a broadcast system, then CDMA, FDMA, and TDMA all have the same rate regions. Finally, without interference cancellation CDMA is generally inferior to both FDMA and TDMA. Although CDMA with interference cancellation is always at least as good as the other techniques, it also requires more complexity in both the transmitter and receiver, which may preclude its use in low-power mobile receivers [4]. We conclude with a discussion of power control and intercell interference.

2 Single-User Time-Varying Channels

It has been shown [5] that for a single-user time-varying channel, if the channel variation is tracked at the transmitter then assuming no complexity or delay constraints, the efficiency is maximized by adapting three parameters to the channel variation: transmit power, data rate, and coding scheme. For time-varying impulse response channels, this adaptive scheme implies that the capacity-achieving input spectrum $S(f,t)$ is derived using "water-filling" in time and frequency, as shown by the shaded region in Figure 1. Specifically, if the channel spectrum varies with time as $H(f,t)$, then the capacity-achieving input spectrum is Gaussian with power inversely proportional to $\Lambda - N_0/|H(f,t)|^2$, where the constant Λ is determined from the average power constraint. This figure is analogous to the frequency "water-filling" derived by Gallager for time-invariant channels [6]. The intuition is that when a portion of the channel bandwidth is favorable (i.e. low noise or interference), more power and data bits should be allocated to it. The expression "water-filling" comes from the idea that the inverse channel spectrum $N_0/|H(f,t)|^2$ forms the bottom of a container into which water (power) is poured up to the level Λ, and the resulting water shape forms the optimal transmit power spectrum. Note that this optimal spectrum requires transmission of different power levels across the signal spectrum, in contrast to power control policies which adjust the transmit power uniformly across frequencies. This type of "water-filling" power allocation is currently used in the HDSL standard.

For flat-fading channels, the time-varying channel reduces to an AWGN channel with a multiplicative power gain $g(t)$. The capacity-achieving transmit signal in this

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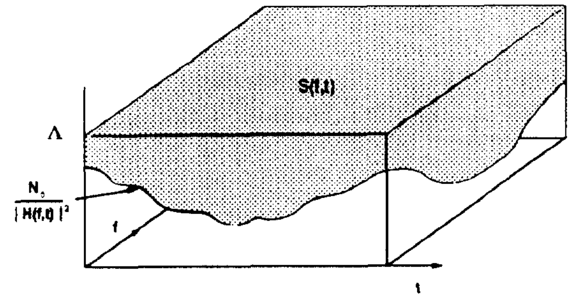

Figure 1: Water-Filling in Time and Frequency.

case reduces to a Gaussian signal with power $P_g = \Lambda - \alpha/g$ for $g > g_{min}$, where $1/\alpha$ is the expected value of the channel gain g [7]. The capacity corresponding to this power control is given by [7]

$$C = B \int \log_2 \left[1 + P_g g\right] \pi(g) dg, \tag{1}$$

where $\pi(g)$ is the distribution of the channel gain g. Intuitively, when the channel is favorable (g large), more power is transmitted. The transmit power is decreased as g decreases, and below the threshold g_{min} the channel is not used at all.

3 Memoryless AWGN Channel Rate Regions

When several users share the same channel, the channel capacity can no longer be characterized by a single number. At the extreme, if all but one user occupies the channel, then the single-user capacity results of the previous section apply. However, since there is an infinite number of ways to "divide" the channel between many users, the multiuser channel capacity is characterized by a *rate region*, where each point in the region is a vector of achievable rates that can be maintained by all the users simultaneously. The set of all achievable rates is called the *capacity region* of the multiuser system. In this section we analyze two time-invariant memoryless AWGN channels: the broadcast channel and the multiaccess channel. We examine rate regions for these channels using CDMA with and without interference cancellation, TDMA, and FDMA spectrum-sharing techniques. Most of these results were derived by Cover or Bergmans: more details and further references can be found in [8]. The maximum rate region, achieved using CDMA with interference cancellation, relies on the concept of superposition codes and successive decoding [9]. We will elaborate on this technique in the following sections. We will also show that the rate region of CDMA without interference cancellation is inferior to all the other spectrum-sharing techniques. As in the single-user case, the capacity region gives the maximum set of rates without constraint on the complexity and delay of the coding, decoding, and spectrum-sharing method.

3.1 Broadcast Channels

The broadcast channel consists of one transmitter sending information to many receivers over a common channel. The capacity region of the broadcast channel characterizes how much information can be conveyed to the different receivers simultaneously. We consider rate regions for a two-user discrete AWGN broadcast channel only; the extension to multiple users is straightforward [9]. Thus, there is one sender of power P, and two distant receivers, each with AWGN of power n_i, $i = 1, 2$. We also assume that the data pulses are Nyquist, so the signal bandwidth $B = 1/T$, where T denotes the length of each data pulse. Let $n_1 \leq n_2$, so receiver 1's channel is less noisy than receiver 2's, and let R_i denote the rate of transmission to receiver i. The rate regions for time-division, frequency-division, and code-division (superposition coding) with and without interference cancellation are illustrated in Figure 2. We now summarize the derivation of these rate regions.

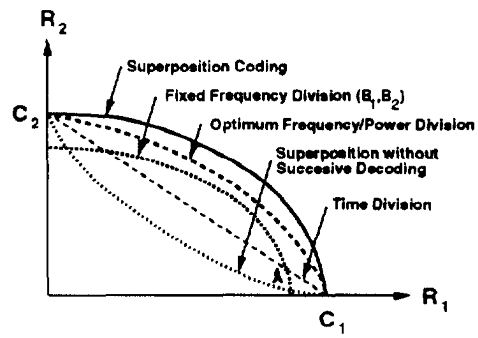

Figure 2: Broadcast Channel Rate Region.

If we denote the total power and bandwidth allocated to both users by P and B, respectively, then the single-user capacity C_i of receiver i's channel is given by:

$$C_i = \frac{B}{2} \log \left[1 + \frac{P}{n_i B}\right]. \tag{2}$$

If the transmitter allocates all the power and bandwidth to one of the users, then the other user receives no data; therefore, the set of simultaneously achievable rates (R_1, R_2) includes the pairs $(C_1, 0)$ and $(0, C_2)$, which bounds the multiuser capacity region. We now consider rate pairs in the interior of the region, which are achieved using more equitable methods of dividing the channel resources.

In time-division, the full power and bandwidth is allocated to user 1 for a fraction τ of the total transmission time, and then to user 2 for the remainder of the transmission. This time division scheme achieves the straight line in Figure 2 corresponding to the rate pairs $(\tau C_1, (1-\tau)C_2)$. An alternative approach for spectrum-sharing is frequency division. In this method the ith user is allocated power P_i and bandwidth B_i of the total, so $P_1 + P_2 = P$ and $B_1 + B_2 = B$. The set of achievable rates (R_1, R_2), for fixed P_i and B_i, is then given by

$$R_i \leq \frac{B_i}{2} \log \left[1 + \frac{P_i}{n_i B_i} \right]. \qquad (3)$$

It was shown by Bergmans [9] that, for n_1 strictly less than n_2 and any fixed frequency division (B_1, B_2), there exists a range of power allocations (P_1, P_2) whose corresponding rate pairs dominate a segment of the time division rate region, as illustrated in Figure 2. Thus, the rate regions achievable through time division can always be exceeded by optimizing both the frequency and power allocation in (3). The intersection point A of time- and frequency-division in Figure 2 corresponds to a power allocation P_i that is proportional to the bandwidth B_i. It can also be shown [9] that time-division with different power allocated to the two users has the same rate region as frequency-division with this variable power.

The rate region using superposition coding and successive decoding was derived in [9] to be the convex hull of rate pairs

$$\begin{aligned} R_1 &= \frac{B}{2} \log \left[1 + \frac{\alpha_1 P}{n_1 B} \right], \\ R_2 &= \frac{B}{2} \log \left[1 + \frac{\alpha_2 P}{n_2 B + \alpha_1 P} \right], \end{aligned} \qquad (4)$$

where $\alpha_1 + \alpha_2 = 1$. The intuitive explanation for (4) is the following. Since $n_1 < n_2$, user 1 correctly receives all the data transmitted to user 2. Therefore, user 1 can correctly decode and then subtract out user 2's message, then decode its own message. User 2 cannot decode the message intended for user 1, since it has a less-favorable channel; thus, user 1's message, with power $\alpha_1 P$, contributes an additional noise term to user 2's received message.

The rate region defined by (4) was shown in [10] to strictly dominate the regions achievable through either time or frequency division, when $n_1 < n_2$. Moreover, Bergmans shows in [10] that (4) defines the capacity region, i.e., the maximum achievable set of rate pairs. However, superposition coding is superior only when $n_1 \neq n_2$; otherwise, all the spectrum-sharing methods we have described have the same rate region [10].

In practice, successive decoding of superposition codes adds complexity and delay in the decoding process, as well as the potential for feedback errors when user 2's message is not decoded properly. Superposition coding is mostly done using spread spectrum techniques [1], and successive decoding for this implementation is generally too complex to build into a low-power portable device [4]. Most commercial spread spectrum receivers don't use successive decoding: they treat all messages intended for other users as noise, resulting in a rate region (R_1, R_2) satisfying

$$\begin{aligned} R_1 &\leq \frac{B}{2} \log \left[1 + \frac{\alpha_1 P}{n_1 B + \alpha_2 P} \right], \\ R_2 &\leq \frac{B}{2} \log \left[1 + \frac{\alpha_2 P}{n_2 B + \alpha_1 P} \right], \end{aligned} \qquad (5)$$

where $\alpha_1 + \alpha_2 = 1$. By taking second derivatives of R_1 and R_2 with respect to α_1, we see that (R_1, R_2) as a function of α_1 is convex, with end points C_1 and C_2, as shown in Figure 2. Therefore, *both time division and frequency division always dominate superposition coding without successive decoding*. The fixed frequency division scheme also dominates this suboptimal technique over some range of rate regions, in particular the shaded region shown in Figure 2.

3.2 Multiaccess Channels

The multiaccess channel consists of K transmitters sending information to one receiver over a common channel of bandwidth B. The transmitters must encode their individual signals such that they can be determined from the received signal, which consists of the sum of signals from each transmitter. The rate region of the multiaccess channel characterizes how much information can be received simultaneously from all the transmitters.

The multiaccess model consists of several transmitters, each with power P_i, sending to a receiver which is corrupted by AWGN of power n. If we denote the ith transmitted signal by X_i, then the received signal is given by $Y = \sum_{i=1}^{K} X_i + N$, where N is an AWGN sample of power n. The two-user multiaccess capacity region was determined by Cover to be the closed convex hull of all vectors (R_1, R_2) satisfying [8]

$$\begin{aligned} R_i &\leq \frac{B}{2} \log \left[1 + \frac{P_i}{nB} \right], \\ R_1 + R_2 &\leq \frac{B}{2} \log \left[1 + \frac{P_1 + P_2}{nB} \right]. \end{aligned} \qquad (6)$$

This region is shown in Figure 3, where C_i and C_i^* are given by

$$C_i = \frac{B}{2} \log \left[1 + \frac{P_i}{nB} \right], \; i = 1, 2, \qquad (7)$$

$$C_1^* = \frac{B}{2} \log \left[1 + \frac{P_1}{nB + P_2} \right], \qquad (8)$$

and

$$C_2^* = \frac{B}{2} \log \left[1 + \frac{P_2}{nB + P_1} \right]. \qquad (9)$$

The point $(C_1, 0)$ is the achievable rate vector when transmitter 1 is sending at its maximum rate and transmitter 2 is silent, and the opposite scenario achieves the rate vector $(0, C_2)$. The corner points (C_1, C_2^*) and (C_1^*, C_2) are achieved using the successive decoding technique described above for superposition codes. Specifically, let the first user operate at the maximum data rate C_1. Then its signal will appear as noise to user 2; thus, user 2 can send data at rate C_2^* which can be decoded at the receiver with arbitrarily small error probability. If the receiver then subtracts out user 2's message from its received signal, the remaining message component is just users 1's message corrupted by noise, so rate C_1 can be achieved with arbitrarily small error probability. Hence, (C_1, C_2^*) is an

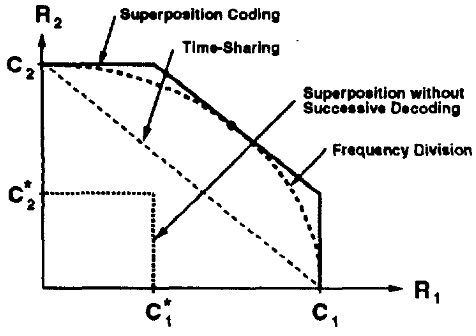

Figure 3: Multiaccess Channel Rate Region.

achievable rate vector. A similar argument with the user roles reversed yields the rate point (C_1^*, C_2).

Time division between the two transmitters operating at their maximum rates, given by (7), yields any rate vector on the straight line connecting C_1 and C_2. With frequency division, the rates depend on the fraction of the total bandwidth that is allocated to each transmitter. Letting B_1 and B_2 denote the bandwidth allocated to each of the two users, we get the rate region (R_1, R_1) with

$$R_i \leq \frac{B_i}{2} \log \left[1 + \frac{P_i}{nB_i}\right]. \qquad (10)$$

Clearly this region dominates time division, since setting $B_1 = \tau B$ and $B_2 = (1-\tau)B$ in (10) yields a higher rate region (R_1, R_1) than $(\tau C_1, (1-\tau)C_2)$. Varying the values of B_1 and B_2 subject to the constraint $B_1 + B_2 = B$ yields the frequency division curve shown in Figure 3. It can be shown [8] that this curve touches the rate region boundary at one point, and this point corresponds to the rate vector which maximizes the sum $R_1 + R_2$. To achieve this point, the bandwidths B_1 and B_2 must be proportional to their corresponding powers P_1 and P_2.

As with the broadcast multiuser channel, we can achieve the same rate region with time division as with frequency division by efficient use of the transmit power. If we take the constraints P_1 and P_2 to be average power constraints, then since user i only uses the channel τ_i percent of the time, its average power over that time fraction can be increased to P_i/τ_i. The rate region achievable through time division is then given by (R_1, R_2) with

$$R_i \leq \tau_i \frac{B}{2} \log \left[1 + \frac{P_i}{n\tau_i B}\right], \; i = 1, 2, \qquad (11)$$

and substituting $B_i \triangleq \tau_i B$ in (11) yields the same rate region as in (10).

Superposition codes without successive decoding can also be used. With this approach, each transmitter's message acts as noise to the others. Thus, the maximum achievable rate in this case cannot exceed (C_1^*, C_2^*), which is clearly dominated by frequency division for some bandwidth allocations, in particular the allocation that intersects the rate region boundary. More work is needed to determine when, if ever, this suboptimal technique achieves better rates than time or frequency division.

4 Time-Varying Rate Regions

In the previous two sections, we analyzed the rate regions for multiuser time-invariant channels. We now consider the maximum achievable rates for time-varying multiuser channels with channel estimation and transmitter feedback. The rate regions for such channels combine the superposition coding ideas with the single-user power control techniques outlined in §2.

4.1 Narrowband Broadcast AWGN Channels

The two-user time-varying narrowband broadcast channel has one sender with time-varying power $P(t)$ and bandwidth B, and two receivers with AWGN of time-varying power $n_i(t), i = 1, 2$. The ith receiver tracks the noise level $n_i(t)$, and the transmitter tracks both $n_1(t)$ and $n_2(t)$. The transmitter can vary its instantaneous power $P(t)$ relative to n_1 and n_2, subject only to the average power constraint $\overline{P(t)} = P$.

We first consider the time division method of sharing the common channel bandwidth. In this case, we allocate average transmit power P and bandwidth B to the first user over the time interval $[0, \tau T]$ and to the second user over the time interval $[\tau T, T]$. This method reduces the two-user channel to two orthogonal time-varying single-user channels, so we can use the time-varying channel capacity formula (1) from §2. Thus, we can achieve any rate point $(R_1, R_2) = (\tau C_1(P), (1-\tau)C_2(P)), \quad 0 \leq \tau \leq 1$ where $C_i(P), i = 1, 2$, is given by (1). Substituting (1) into the rate expression yields

$$C_i(P) = \max_{\{\Phi_{j_i}\}} \sum_{n_{j_i}: p(n_i(t) = n_{j_i} > 0)} \pi_{j_i} C_{j_i}(\Phi_{j_i}), \qquad (12)$$

where $\pi_{j_i} = p(n_i(t) = n_{j_i})$, $C_{j_i}(\Phi_{j_i})$ equals the capacity of a time-invariant AWGN channel with noise power n_{j_i}, bandwidth B, and average signal power Φ_{j_i}, and the Φ_{j_i}s are subject to the single-user power constraint $\sum \pi_{j_i} \Phi_{j_i} \leq P$. Using (12) in the rate expression yields the the time division rate region (R_1, R_2) with

$$R_i \leq \max_{\Phi_{j_i}} \sum_{n_{j_i}} \pi_{j_i} \tau C_{j_i}(\Phi_{j_i}), \qquad (13)$$

where the maximization over Φ_{j_i} is subject to the single-user power constraint. The time-varying power of each user can be optimized independently, since time division renders the two users orthogonal.

Fixed frequency division, which divides the total channel bandwidth B into nonoverlapping segments B_1 and B_2, also reduces the two-user channel to independent single-user channels. The total average power P can be divided between the two users in any way such that their power sum $P_1 + P_2 = P$. For P_1 and P_2 fixed, the rate region

(R_1, R_2) then satisfies

$$R_i \leq \max_{\Phi_{j_i}} \sum_{n_{j_i}} \pi_{j_i} C_{j_i}(\Phi_{j_i}, B_i), \tag{14}$$

where $C_{j_i}(\Phi_{j_i}, B_i)$ denotes the capacity of a time-invariant AWGN channel with noise power n_{j_i}, average signal power Φ_{j_i}, and bandwidth B_i, and the maximization is subject to the power constraint $\sum \pi_{j_i} \Phi_{j_i} = P_i$.

As in the time-invariant case, the time division rate region will dominate the fixed frequency division rate region over some range of power allocations P_1 and P_2, in particular when all of the power is allocated to one of the frequency bands (e.g. $P_1 = P, P_2 = 0$). We show in [5] that the fixed frequency division rate region intersects the time division line at the point where the power allocation between the two channels is proportional to the bandwidth. This was also true in the time-invariant case.

However, if we allow both the power and the bandwidth partition to vary, then the resulting rate region dominates both fixed frequency division and time division. The achievable rates in this case are given by

$$(R_1, R_2) = \sum (\pi_{j_1} C_{j_1}(\Phi_{j_1}, B_{j_1}), \pi_{j_2} C_{j_2}(\Phi_{j_2}, B_{j_2})), \tag{15}$$

maximized over all sets of $(\Phi_{j_1}, \Phi_{j_2}, B_{j_1}, B_{j_2})$ which satisfy the power and bandwidth constraints $\sum \pi_{j_1} \Phi_{j_1} + \pi_{j_2} \Phi_{j_2} = P$ and $B_{j_1} + B_{j_2} = B$ for all j_i. Both the power and bandwidth allocations are optimized jointly to achieve the maximum in (15), so the two users are no longer independent. Clearly, any rate point achievable with fixed frequency division can also be achieved with this scheme. It can also be show that (15) dominates time division [5].

The idea of reallocating bandwidth as the channel varies is closely related to dynamic channel allocation, where each user measures the noise (and interference) in a particular frequency band, and only occupies the frequency band if the noise is below some threshold [11]. Suppose two users want to access the same frequency band, and the noise level is below threshold for both, but lower for one of the users. The frequency allocation of (15) suggests that instead of using a threshold level to determine which user should occupy the channel (which for this example would not differentiate between the two users), the channel is allocated to the user which gets the most capacity from it.

We now consider superposition coding, where both users occupy the full channel bandwidth over all time. Since superposition codes dominate time and frequency division in the time-invariant case, we expect this to be true for time-varying channels as well. Indeed, consider any achievable rate point in the frequency division rate region (15). Associated with that point will be a set of frequency divisions (B_{j_1}, B_{j_2}) and a set of transmit power values (Φ_{j_1}, Φ_{j_2}) for all possible noise realizations (n_{j_1}, n_{j_2}). Let $\Phi_j = \Phi_{j_1} + \Phi_{j_2}$. From §4.1 there exists a superposition code with total power Φ_k that dominates the frequency division code for this particular realization (n_{j_1}, n_{j_2}). Since we can find such a dominating code for all realizations, the weighted sum of the superposition rates dominates the frequency division sum. To summarize, the time-varying rate region will have the same relative performance and the time-invariant rate region of Figure 2, and is obtained by taking a weighted average of these time-invariant rate regions, with the wieghts determined by the probability distribution of the noise pairs n_{j_1}, n_{j_2}).

4.2 Narrowband Multiaccess AWGN Channels

The two-user time-varying narrowband multiaccess channel has two transmitters with average power P_1 and P_2, respectively, and one receiver with bandwidth B and AWGN of time-varying power $n(t)$. Let $\pi_n = p(n(t) = n)$ We also assume that transmitter i tracks $n_i(t)$, and the receiver tracks both $n_1(t)$ and $n_2(t)$. The transmitters may vary their instantaneous transmit power $P_i(t)$ relative to $n(t)$, subject only to the average power constraint $\overline{P_i(t)} = P_i$ for $i = 1, 2$.

We first consider spectrum sharing through time division. With this technique we can achieve any point $(R_1, R_2) = \sum \pi_n \left(\tau C_n(\Phi_{n_1}), (1 - \tau) C_n(\Phi_{n_2})\right)$, where

$$C_n(\Phi_{n_i}) \triangleq \frac{B}{2} \log \left[1 + \frac{\Phi_{n_i}}{nB}\right], \tag{16}$$

and Φ_{n_i}, the power allocated to the ith user when $n(t) = n$, is subject to the average power constraint $\sum \pi_n \Phi_{n_i} = P_i$. The Φ_{n_i}s can be optimized independent of each other, since under time division the two users are orthogonal. Optimizing these power allocations subject to the power constraint therefore defines a straight line connecting the points $C_1(P_1)$ and $C_2(P_2)$, where

$$C_i(P_i) = \max_{\{\Phi_{n_i} : \sum \pi_n \Phi_{n_i} = P_i\}} \sum \pi_n C_n(\Phi_{n_i}). \tag{17}$$

Fixed frequency division partitions the total bandwidth B into nonoverlapping segments B_1 and B_2, which are then allocated to the respective transmitters. Since the bandwidths are separate, the users are independent, and they can allocate their time-varying power independently, subject only to the total power constraint P_i. The fixed frequency division rate region (R_1, R_2) thus satisfies

$$R_1 \leq \max_{\Phi_{n_i}} \sum \pi_n C_n(\Phi_{n_i}, B_i), \tag{18}$$

where

$$C_n(\Phi_{n_i}, B_i) = \frac{B_i}{2} \log \left[1 + \frac{\Phi_{n_i}}{nB_i}\right], \tag{19}$$

and the Φ_{n_i}s satisfy the power constraint $\sum \pi_n \Phi_{n_i} = P_i$.

It can be shown [5] that fixed frequency division dominates time division by allocating power in such a way that the time-invariant fixed frequency division rate region dominates the time-division region for all values of $n(t)$, hence on the weighted sum of regions corresponding to variations in $n(t)$. Finally, for any point on the boundary of the frequency division rate region, there is a corresponding bandwidth partition (B_1, B_2) and a set of transmit power values (Φ_{n_1}, Φ_{n_2}) for each value of n. Then from §3.2, a superposition code can achieve any rate point

$$\begin{aligned} R_i &= \frac{B}{2}\log\left[1+\frac{\Phi_{n_i}}{nB}\right], \\ R_1+R_2 &= \frac{B}{2}\log\left[1+\frac{\Phi_{n_1}+\Phi_{n_2}}{nB}\right], \end{aligned} \quad (20)$$

and within this region there is a rate point which dominates frequency division for noise power n. Since superposition can dominate any fixed frequency-division point, optimal allocation of power between the two users relative to $n(t)$ using superposition coding will dominate a similar optimization using frequency division. Thus, as for the multiaccess channel, the relative performance of the different spectrum sharing techniques is the same for time-varying channels as for time-invariant channels, and is given by a weighted average of the rate region in Figure 3.

5 Intercell Interference and Power Control

The analysis above has been for a single cell, and has ignored the impact of intercell interference. It is not clear how to extend the the information theoretic formulations for single-user and multiuser channel capacity to include spatial reuse. However, the optimal power control policy obtained in §2 tends to reduce the impact of intercell interference, since users that are on the cell boundaries will generally have a weak channel. Therefore, under this optimal policy, they transmit at a lower power, which reduces the amount of interference that couples into neighboring cells. The impact of different power control policies on intercell interference is discussed in more detail in [5].

6 Conclusions

We've compared the capacity of multiuser time-varying cellular channels under different spectrum-sharing techniques. We've shown that superposition coding with successive decoding and optimized power control maximizes the capacity region for both broadcast and multiaccess channels. Frequency-division and time-division have equal rate regions if transmit power is varied according to the changing channel and which user is currently occupying it. In addition, dynamic channel (or timeslot) allocation will increase the efficiency of channel use. Finally, superposition coding without successive decoding has the smallest rate region, but also the lowest complexity, since there is no dynamic allocation of power, bandwidth, or timeslots.

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