FAWNA: A high-speed mobile communication network architecture*

(Invited Paper)

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ABSTRACT

The concept of a fiber aided wireless network architecture (FAWNA) is introduced in [Ray et al., Allerton 2005], which allows high-speed mobile connectivity by leveraging the speed of optical networks. In this paper, we consider a single-input, multiple-output (SIMO) FAWNA, which consists of a SIMO wireless channel interfaced to an optical fiber channel, through wireless-optical interfaces. We propose a scheme where the received wireless signal at each interface is quantized and sent over the fiber. The capacity of our scheme approaches the capacity of the architecture, exponentially with fiber capacity. We show that for a given fiber capacity, there is an optimal operating wireless bandwidth and an optimal number of wireless-optical interfaces. We also address the question of how fiber capacity should be divided between the interfaces. We show that an optimal allocation is one which ensures that each interface gets at least that fraction of the fiber capacity which ensures that its noise is dominated by front end noise rather than by quantizer distortion. After this requirement is met, SIMO-FAWNA capacity is almost invariant to allocation of left over fiber capacity. The wireless-optical interfaces of our scheme have low complexity and do not require knowledge of the transmitter code book. They are also extendable to FAWNAs with large number of transmitters and interfaces and, offer adaptability to variable rates, changing channel conditions and node positions.

1. INTRODUCTION

There is a considerable demand for increasingly high-speed communication networks with mobile connectivity. Traditionally, high-speed communication has been efficiently provided through wireline infrastructure, particularly based on optical fiber, where bandwidth is plentiful and inexpensive. However, such infrastructure does not support mobility. Instead, mobile communication is provided by wireless infrastructure, most typically over the radio spectrum. However, limited available spectrum and interference effects limit mobile communication to lower data rates.

We introduce the concept of a fiber aided wireless network architecture (FAWNA) in [10], which allows high-speed mobile connectivity by leveraging the speed of optical networks. Optical networks have speeds typically in hundreds of Megabit per sec or several Gigabit per sec (Gigabit Ethernet, OC-48, OC-192, etc.). In the proposed architecture, the network coverage area is divided into zones such that an optical fiber "bus" passes through each zone. Connected to the end of the fiber is a bus controller/processor, which coordinates use of the fiber as well as connectivity to the outside world. Along the fiber are radio-optical converters (wireless-optical interfaces), which are access points consisting of simple antennas directly connected to the fiber. Each of these antennas harvest the energy from the wireless domain to acquire the full radio bandwidth in their local environment and place the associated waveform onto a subchannel of the fiber. Within the fiber, the harvested signals can be manipulated by the bus controller/processor and made available to all other antennas. In each zone, there may be one or more active wireless nodes. Wireless nodes communicate between one another, or to the outside world, by communicating to a nearby antenna. Thus any node in the network is at most two hops away from any other node, regardless of the size of the network. In general, each zone is generally covered by several antennas, and there may also be wired nodes connected directly to the fiber.

This architecture has the potential to reduce dramatically the interference effects that limit scalability and the energy-consumption characteristics that limit battery life, in pure wireless infrastructure. A FAWNA uses the wireline infrastructure to provide a distributed means of aggressively harvesting energy from the wireless medium in areas where there is a rich, highly vascularized wireline infrastructure and distributing in an effective manner energy to the wireless domain by making use of the proximity of transmitters to reduce interference.

In this paper, we consider a single-input, multiple-output (SIMO) fiber aided wireless network architecture. We will

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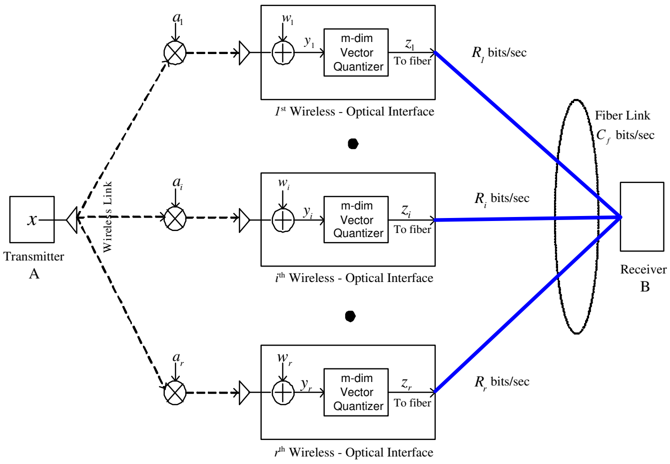

Figure 1: A SIMO fiber aided wireless network architecture.

also refer to this as SIMO-FAWNA. Figure 1 shows such a link between two points A and B. The various quantities in the figure will be described in detail in the next section. In the two hop link, the first hop is over a wireless channel and the second, over a fiber optic channel. The links we consider are ones where the fiber optic channel capacity is larger than the wireless channel capacity.

The transmitter at A transmits information to intermediate wireless-optical interfaces over a wireless SIMO channel. The wireless-optical interfaces then relay this information to the destination, B, over a fiber optic channel. The end-to-end design is done to maximize the transmission rate from A to B. Since a FAWNA has a large number of wireless-optical interfaces, an important design objective is to keep the wireless-optical interface as simple as possible without sacrificing too much in performance.

Our problem has a similar setup, but a different objective than the CEO problem [9]. In the CEO problem, the rate-distortion tradeoff is analyzed for a given source that needs to be conveyed to the CEO through an asymptotically large number of agents. Rate-distortion theory, which uses infinite dimensional vector quantization, is used to analyze the problem. We instead compute the maximum end-to-end rate at which reliable communication is possible. In general, duality between the two problems doesn't exist. Unlike the CEO problem, the number of wireless-optical interfaces is finite and the rate (from interface to receiver B) per interface is high due to the fiber capacity being large. Finite-dimensional, high resolution quantizers are used at the interfaces.

Let us denote the capacities of the wireless and optical channels as $C_w(P, W, r)$ and C_f bits/sec, respectively, where, P is the average transmit power at A, W is the wireless transmission bandwidth and r is the number of wireless-optical interfaces. Since, as stated earlier, we consider links where $C_w(P, W, r) \leq C_f$, the capacity of a SIMO-FAWNA, $C_{\mathsf{SIMO}}(P, W, r, C_f)$, can be upper bounded as

$$C_{\mathsf{SIMO}}(P, W, r, C_f) < \min\left\{C_w(P, W, r), C_f\right\} = C_w(P, W, r) \text{ bits/sec.} \quad (1)$$

One way of communicating over a SIMO-FAWNA is to decode and re-encode at the wireless-optical interfaces. A major drawback of the decode/re-encode scheme is significant loss in optimality because "soft" information in the wireless signal is completely lost by decoding at the wireless-optical interfaces. Hence, multiple antenna gain is lost. Moreover, decoding results in the wireless-optical interface having high complexity and the interface requires knowledge of the transmitter code book.

In this paper, we propose a scheme where the wireless signal at each wireless-optical interface is sampled and quantized using a fixed-rate, memoryless, vector quantizer, before being sent over the fiber. Hence, the interfaces use a forwarding scheme. Since transmission of continuous values over the fiber is practically not possible using commercial lasers, quantization is necessary for the implementation of a forwarding scheme in a FAWNA. The proposed scheme thus has quantization between the end-to-end coding and decoding. Knowledge of the transmitter code book is not required at the wireless-optical interface. The loss in "soft" information due to quantization of the wireless signal, goes to 0 asymptotically with increase in fiber capacity. The interface has low complexity, is practically implementable, is extendable to FAWNAs with large number of transmitters and interfaces and, offers adaptability to variable rates, changing channel conditions and node positions.

We show that the capacity using our scheme approaches the upper bound (1), exponentially with fiber capacity. The proposed scheme is thus near-optimal since the fiber capacity is larger than the wireless capacity. Low dimensional (or even scalar) quantization can be done at the interfaces without significant loss in performance. Not only does this result in low complexity, but also smaller (or no) buffers are required, thereby further simplifying the interface. Hui and Neuhoff [8] show that asymptotically optimal quantization can be implemented with complexity increasing at most polynomially with the rate. For a SIMO-FAWNA with fixed fiber capacity, quantizer distortion as well as wireless capacity, $C_w(P, W, r)$, increases with wireless bandwidth and number of interfaces. The two competing effects result in the existence of an optimal operating wireless bandwidth and an optimal number of wireless-optical interfaces. We also address the problem of interface rate allocation and investigate the robustness of SIMO-FAWNA capacity to this allocation.

This paper is organized as follows: In section 2, we describe our model and communication scheme. We analyze interface rate allocation and performance of our scheme in sections 3 and 4, respectively. We conclude in section 5. Unless specified otherwise, all logarithms in this paper are to the base 2.

2. MODEL & COMMUNICATION SCHEME

There are r wireless-optical interfaces and each of them is equipped with a single antenna. The interfaces relay the wireless signals they receive from the transmitter at A to the receiver at B, over an optical fiber. Communication over the fiber is interference free, which may be achieved, for example, using Time Division Multiple Access (TDMA) or Frequency Division Multiple Access (FDMA).

2.1 Wireless Channel

We use a linear model for the wireless channel between A and the wireless-optical interfaces:

$$\vec{\mathbf{y}} = \vec{a}\mathbf{x} + \vec{\mathbf{w}},$$

where, $\mathbf{x} \in \mathcal{C}, \vec{\mathbf{w}}, \vec{\mathbf{y}} \in \mathcal{C}^r$ are the channel input, additive noise and output, respectively. The channel gain vector (state), $\vec{a} \in \mathcal{C}^r$, is fixed and perfectly known at the receiver. a_i denotes the channel gain for the i^{th} interface. The additive noise is a zero mean circularly symmetric complex Gaussian random vector, $\vec{\mathbf{w}} \sim \mathcal{CN}(0, N_0 I_r)$, and is independent of the channel input. $N_0/2$ is the double-sided white noise spectral density. The channel input, $\mathbf{x}$, satisfies the average power constraint

$$E[|\mathbf{x}|^2] = \frac{P}{W},$$

where, P and W are the average transmit power at A and wireless bandwidth, respectively. Hence, the wireless channel capacity is

$$C_w(P, W, r) = W \log\left(1 + \frac{\|\vec{a}\|^2 P}{N_0 W}\right),$$

and W symbols/sec are transmitted over the wireless channel. Using (1), we obtain an upper bound to the SIMO-FAWNA capacity:

$$C_{\mathsf{SIMO}}(P, W, r, C_f) < W \log\left(1 + \frac{\|\vec{a}\|^2 P}{N_0 W}\right). \tag{2}$$

2.2 Fiber Optic Channel

The fiber optic channel between the wireless-optical interfaces and the receiver at B, can reliably support a rate of C_f bits/sec. Communication over the fiber is interference free and the i^{th} interface communicates at a rate of R_i bits/sec with receiver B. Now,

$$0 < R_i \leq C_f \qquad \text{for } i \in \{1, \ldots, r\}, \tag{3}$$

$$\sum_{i=1}^{r} R_i = C_f. \tag{4}$$

Let us define the set of all rate vectors satisfying these two constraints (3, 4) as $\mathcal{S}$. Fiber channel coding is performed at the wireless-optical interface to reliably achieve the rate vectors in $\mathcal{S}$. Note that the code required for the fiber is a very low complexity one. An example of a code that may be used is the 8B10B code, which is commonly used in Ethernet. Hence, fiber channel coding does not significant increase the complexity at the wireless-optical interface. In this work, we assume error free communication over the fiber for all sum rates below fiber capacity. To keep the interfaces simple, source coding is not done at the interfaces. We show later that since fiber capacity is large compared to the wireless capacity, the loss from no source coding is negligible.

2.3 Communication Scheme

The input to the wireless channel, $\mathbf{x}$, is a zero mean circularly symmetric complex Gaussian random variable, $\mathbf{x} \sim \mathcal{CN}(0, P/W)$. Note that it is this input distribution that achieves the capacity of our wireless channel model. At each wireless-optical interface, the output from the antenna is first converted from passband to baseband and then sampled at the Nyquist rate of W complex samples/sec. The random variable, $\mathbf{y}_i$, represents the output from the sampler at the i^{th} interface. Fixed-rate, memoryless, m-dimensional vector quantization is performed on these samples at a rate of R_i/W bits/complex sample. The quantized complex samples are subsequently sent over the fiber after fiber channel coding and modulation. Thus, the fiber is required to reliably support a rate of R_i bits/sec from the i^{th} wireless-optical interface to the receiver at B.

The quantizer noise at the i^{th} interface, $\mathbf{q}_i$, is modeled as being additive. Hence, the two-hop channel between A and B can be modeled as:

$$\vec{\mathbf{z}} = \vec{a}\mathbf{x} + \vec{\mathbf{w}} + \vec{\mathbf{q}},$$

where, $\vec{\mathbf{q}} = [\mathbf{q}_1, \ldots, \mathbf{q}_r]^T$, and ^{T} denotes transpose. Note that the interfaces have noise from two sources, receiver front end and quantizers. The quantizer at the interface is an optimal fixed rate, memoryless, m-dimensional, high resolution vector quantizer. Hence, its distortion-rate function is given by the Zador-Gersho function [1, 3, 5]:

$$\begin{aligned} &E[|\mathbf{q}_i|^2] \\ &\quad = E[|\mathbf{y}_i|^2] M_m \beta_m 2^{-\frac{R_i}{W}} \\ &\quad = \left(N_0 + \frac{|a_i|^2 P}{W}\right) M_m \beta_m 2^{-\frac{R_i}{W}}. \end{aligned} \tag{5}$$

M_m is the Gersho's constant which is independent of the distribution of $\mathbf{y}_i$ and, β_m is the Zador's factor that depends on the distribution of $\mathbf{y}_i$. Since the fiber channel capacity is large, the assumption that the quantizer is a high resolution one, is valid. Hence, for all i, $R_i/W \gg 1$. Also, as this quantizer is an optimal fixed rate memoryless vector quantizer, references [2, 3, 4, 6, 7] show that the following hold: $E[\mathbf{q}_i] = 0$, $E[\mathbf{z}_i \mathbf{q}_i^*] = 0$ and $E[\mathbf{y}_i \mathbf{q}_i^*] = -E[|\mathbf{q}_i|^2]$. Therefore, $E[|\mathbf{z}_i|^2] = E[|\mathbf{y}_i|^2] - E[|\mathbf{q}_i|^2]$.

Observe that the wireless-optical interfaces have low complexity and do not require knowledge of the transmitter code book. They are also extendable to FAWNAs with large number of transmitters and interfaces and, offer adaptability to variable rates, changing channel conditions and node positions.

3. INTERFACE RATE ALLOCATION

In this section, we address the problem of interface rate allocation. For any rate allocation, $\vec{R}$, the capacity of our scheme, $C_{\mathsf{Q}}(P, W, \vec{a}, \vec{R})$, is given by the following theorem (proof omitted for brevity):

THEOREM 1.

$$C_{\mathsf{Q}}(P, W, \vec{a}, \vec{R}) = W \log\left(\frac{1}{1 - \frac{P}{N_0 W} \vec{v}^\dagger M^{-1} \vec{v}}\right) \tag{6}$$

where, $\vec{v}$ is specified for $i \in \{1, \ldots, r\}$ as

$$v_i = a_i (1 - M_m \beta_m 2^{-\frac{R_i}{W}}),$$

and, M is specified for $i \in \{1, \ldots, r\}, j \in \{1, \ldots, r\}$ as

$$\begin{aligned} M_{ij} &= \frac{a_i a_j^* P}{N_0 W}(1 - M_m \beta_m 2^{-\frac{R_i}{W}})(1 - M_m \beta_m 2^{-\frac{R_j}{W}}) \\ &\qquad \text{for } i \neq j, \\ &= \left(1 + \frac{|a_i|^2 P}{N_0 W}\right)(1 - M_m \beta_m 2^{-\frac{R_i}{W}}) \\ &\qquad \text{for } i = j. \end{aligned}$$

□

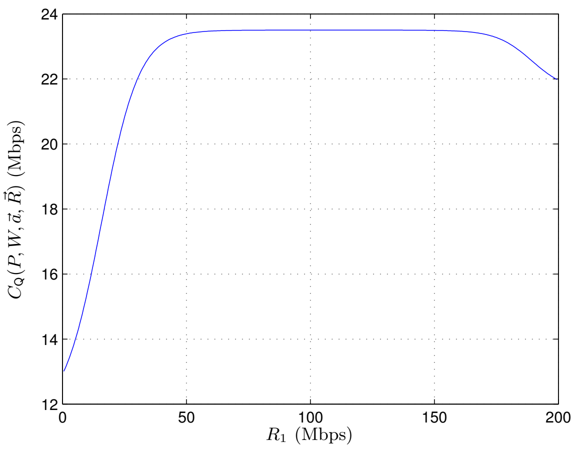

Figure 2: Interface rate allocation for a two interface SIMO-FAWNA.

The optimal rate allocation is given by

$$\vec{R}^*(\vec{a}) = \arg\max_{\vec{R} \in \mathcal{S}} \left[C_\mathsf{Q}(P, W, \vec{a}, \vec{R}) \right],$$

and the capacity of our scheme, $C_\mathsf{Q}(P, W, r, C_f)$, is

$$C_\mathsf{Q}(P, W, r, C_f) \triangleq C_\mathsf{Q}(P, W, \vec{a}, \vec{R}^*(\vec{a})).$$

To understand optimal rate allocation, let us consider a SIMO-FAWNA with two interfaces[1], fiber capacity 200 Mbps, channel state $\vec{a} = [1\ \frac{1}{2}]^T$, $\frac{P}{N_0} = 100 \times 10^6$, $W = 5$ MHz and $M_m \beta_m = 1$. Since $R_2 = C_f - R_1$, it suffices to consider the capacity with respect to R_1 alone. The plot of $C_\mathsf{Q}(P, W, \vec{a}, \vec{R})$ with respect to R_1 is shown in figure 2.

We can divide the plot into three regions. The first region is from 0 Mbps to 50 Mbps where the first interface has low rate[2] and the second has high rate. Thus, noise at the first interface is quantizer distortion dominated whereas at the second interface is front end noise dominated. Hence, as we increase the rate for the first interface, the distortion at the first interface decreases and overall capacity increases. The reduction in rate at the second interface due to increase in R_1 has negligible effect on capacity since front end noise still dominates at the second interface.

The second region is from 50 Mbps to 170 Mbps. In this region, the rates for both interfaces are high enough for front end noise to dominate. Since quantizer distortion is low with respect to the front end noise at both interfaces, capacity is almost invariant to the way in which fiber capacity is divided between the interfaces. Observe that capacity is maximum in this region and the size of this region is much larger than that of the first and third.

The third region is from 170 Mbps to 200 Mbps and here, the first interface has high rate and the second has low rate. Therefore, noise at the first interface is front end noise dominated whereas at the second interface is quantizer distortion dominated. An increase in rate for the first interface results in decrease in rate for the second interface. This decrease in rate leads to an increase in quantizer distortion at the second interface, which results in overall capacity decrease. The channel gain at the first interface is higher than that at the second interface. Hence, compared to the second interface, the first interface requires more rate to bring its quantizer's distortion below the front end noise. Also, reduction in quantizer distortion at the first interface results in higher capacity gains than reduction in quantizer distortion at the second interface. This can been seen from the asymmetric nature of the plot in figure 2 around $R_1 = 100$ Mbps.

We see that optimum interface rate allocation for a FAWNA is to ensure that each interface gets rate enough for it to lower its quantizer distortion to the point where its noise is front end noise dominated. Wireless-optical interfaces seeing higher channel gains require higher rates to bring down their quantizer distortion. After this requirement is met, FAWNA capacity is almost invariant to allocation of left over fiber capacity. This can be seen from the near flat capacity curve in the second region of the plot in figure 2. Thus, any interface rate allocation that ensures that noise at none of the wireless-optical interfaces is quantizer distortion dominated, is optimal.

Since fiber capacity is large compared to the wireless capacity, the fraction of fiber capacity required to ensure that none of the interfaces is quantizer distortion limited, is small. Therefore, the set of interface rate vectors for which capacity is maximum and almost invariant, is large and there is considerable flexibility in allocating rates across the interfaces. Hence, we see that large fiber capacity brings robustness to interface rate allocation in a FAWNA. For example, from figure 2, we see that even an equal rate allocation for the two interface SIMO-FAWNA is near-optimal.

4. PERFORMANCE ANALYSIS

In this section, we analyze the performance of the scheme described in Theorem 1. We examine how the capacity using our scheme (6) is influenced by fiber capacity, transmit power, number of interfaces and wireless bandwidth. In the previous section, we have seen the robustness of FAWNA capacity to interface rate allocation. Hence, an equal rate allocation is near-optimal and, we set

$$R_i = \frac{C_f}{r} \text{ for } i \in \{1, \ldots, r\}.$$

To simplify analysis, we will set the wireless channel gain, $\vec{a} = \vec{1}$, where, $\vec{1}$ is the r dimensional column vector with all ones. Note that equal interface rate allocation for this channel state is optimal. Hence, we can rewrite the capacity of our scheme, $C_\mathsf{Q}(P, W, r, C_f)$, as

$$C_\mathsf{Q}(P, W, r, C_f) = W \log \left(1 + \frac{rP}{N_0 W}\right) - \Phi(P, W, r, C_f),$$

where,

$$\Phi(P, W, r, C_f) = W \log \left(1 + \frac{rP}{N_0 W}\right) - W \log \left(1 + \frac{r(1 - M_m \beta_m 2^{-\frac{C_f}{rW}}) \frac{P}{N_0 W}}{1 + \frac{P M_m \beta_m 2^{-\frac{C_f}{rW}}}{N_0 W}}\right). \quad (7)$$

[1]Even though we consider a two interface SIMO-FAWNA, results generalize to SIMO-FAWNAs with any number of interfaces.

[2]Whenever we mention "low rate", the rate considered is always high enough for the high resolution quantizer model to be valid.

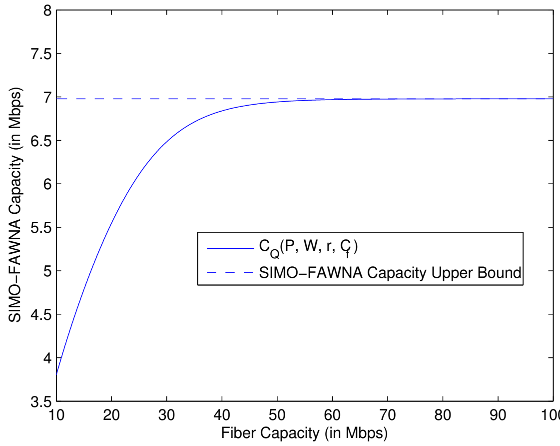

Figure 3: Dependence of SIMO-FAWNA capacity on fiber capacity.

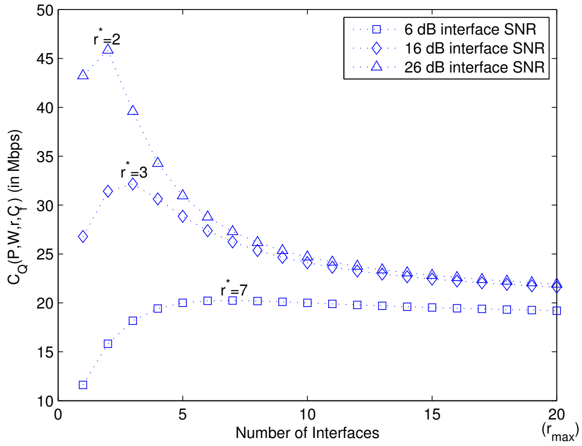

Figure 4: Effect of the number of interfaces on SIMO-FAWNA capacity.

4.1 Effect of fiber capacity

For studying the effect of fiber capacity on the performance of a SIMO-FAWNA, it suffices to consider the function, $\Phi(P, W, r, C_f)$. To make the expressions compact, define $\psi(l) \triangleq \frac{(1-M_m\beta_m 2^{-l})}{1+\frac{PM_m\beta_m 2^{-l}}{N_0 W}}$. Note that $\psi(l) = \Theta(2^{-l})$. Now,

$$\Phi(P, W, r, C_f) = W \log\left(1 + \frac{r[1-\psi(\frac{C_f}{rW})]\frac{P}{N_0 W}}{1 + r\psi(\frac{C_f}{rW})\frac{P}{N_0 W}}\right)$$
$$\leq \frac{P}{N_0} \cdot \frac{r[1-\psi(\frac{C_f}{rW})]\log(e)}{1 + r\psi(\frac{C_f}{rW})\frac{P}{N_0 W}} = O(2^{-C_f}).$$

and

$$\Phi(P, W, r, C_f) \geq \frac{P}{N_0} \cdot \frac{r[1-\psi(\frac{C_f}{rW})]\log(e)}{1 + r\psi(\frac{C_f}{rW})\frac{P}{N_0 W}} - \frac{P^2\log(e)}{2N_0^2 W}\left[\frac{r[1-\psi(\frac{C_f}{rW})]}{1 + r\psi(\frac{C_f}{rW})\frac{P}{N_0 W}}\right]^2 = \Omega(2^{-C_f}).$$

To obtain these bounds, we use $x - \frac{1}{2}x^2 \leq \log_e(1+x) \leq x$. Hence,

$$\Phi(P, W, r, C_f) = \Theta(2^{-C_f}).$$

This implies that the capacity using the proposed scheme approaches the capacity upper bound (2), *exponentially* with quantizer rate. Also, observe that $\Phi(P, W, r, \infty) = 0$. Note that though our scheme simply quantizes and forwards the wireless signals without source coding, it is near-optimal since the fiber capacity is much larger than the wireless capacity. This behavior is illustrated in figure 3, which is a plot of $C_{\mathsf{Q}}(P, W, r, C_f)$ and the upper bound (2), versus fiber capacity. In the plot, we set $W = 1$ Mhz, $M_m\beta_m = 1$, $r = 5$ and $\frac{P}{N_0} = 25 \times 10^6$ sec^{-1}. Note that the fiber capacity required to achieve good performance is not large for an optical fiber, e.g. Gigabit Ethernet, OC-48, etc. which have speeds in the order of Gigabit/sec.

4.2 Effect of transmit power

An increase in transmit power, P, leads to two competing effects. The first is increase in receive power at the interfaces, which increases wireless capacity. The second is increase in quantizer distortion, which reduces wireless capacity. The capacity of our scheme

$$C_{\mathsf{Q}}(P, W, r, C_f) = W \log\left(1 + \frac{r(1 - M_m\beta_m 2^{-\frac{C_f}{rW}})\frac{P}{N_0 W}}{1 + \frac{PM_m\beta_m 2^{-\frac{C_f}{rW}}}{N_0 W}}\right),$$

increases monotonically with $\frac{r(1-M_m\beta_m 2^{-\frac{C_f}{rW}})\frac{P}{N_0 W}}{1+\frac{PM_m\beta_m 2^{-\frac{C_f}{rW}}}{N_0 W}}$, which in turn increases monotonically with P. Hence, the first effect always dominates and $C_{\mathsf{Q}}(P, W, r, C_f)$ *increases* monotonically with transmit power.

4.3 Effect of number of interfaces

Let us focus on the effect of the number of interfaces on $C_{\mathsf{Q}}(P, W, r, C_f)$. Since the quantization rate at the interface is never allowed to go below 1, the maximum number of interfaces possible is $r_{\max} = \lfloor \frac{C_f}{W} \rfloor$. Keeping all other variables fixed, the optimal number of interfaces, r^*, is given by

$$r^* = \arg \max_{r \in \{1,2,\ldots,r_{\max}\}} C_{\mathsf{Q}}(P, W, r, C_f).$$

For fixed wireless bandwidth and fiber capacity, an increase in the number of interfaces leads to two competing effects. First, wireless capacity increases due to receive power gain from the additional interfaces. Second, quantizer distortion increases due to additional interfaces sharing the same fiber, which results in capacity reduction. The quantization rate per symbol decays inversely with r. Hence, capacity doesn't increase monotonically with the number of antennas. Obtaining an analytical expression for r^* is difficult. However, r^* can easily be found by numerical techniques. Figure 4 is a plot of $C_{\mathsf{Q}}(P, W, r, C_f)$ versus r for $W = 5$ Mhz, $M_m\beta_m = 1$, $C_f = 100$ Mbps. Plots are obtained for $\frac{P}{N_0} = 20 \times 10^6$ sec^{-1}, 200×10^6 sec^{-1} and 2000×10^6 sec^{-1}. This corresponds to interface signal-to-noise ratio (SNR) of 6 dB, 16 dB and 20

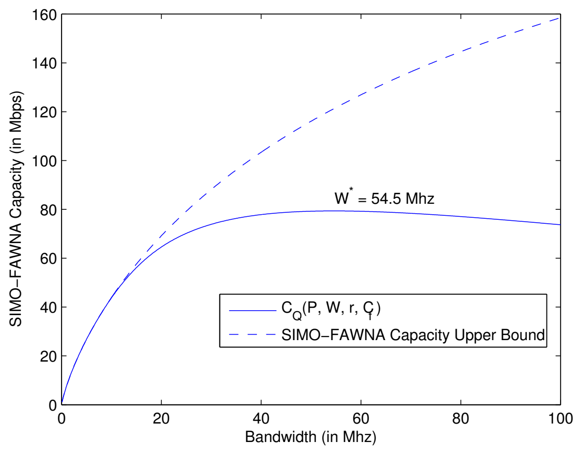

Figure 5: Dependence of SIMO-FAWNA capacity on wireless bandwidth.

dB, respectively. The corresponding values of r^* are 7, 3 and 2, respectively. Observe that r^* decreases with increase in interface SNR. This happens since, when interface SNR is low, it becomes more important to gain power rather than to have fine quantization. On the other hand, when interface SNR is high, the latter is more important. Hence, as interface SNR decreases, r^* tends towards r_{max}.

4.4 Effect of wireless bandwidth

We now analyze the effect of wireless bandwidth, W, on $C_{\mathsf{Q}}(P, W, r, C_f)$. Since the quantization rate is never allowed to go below 1, the maximum possible bandwidth is $\frac{C_f}{r}$. For fixed fiber capacity and number of interfaces, the optimal bandwidth of operation, W^*, is given by

$$W^* = \arg \max_{W \in [0, \frac{C_f}{r}]} C_{\mathsf{Q}}(P, W, r, C_f).$$

Since quantizer distortion as well as power efficiency increases with W, the behavior of capacity with bandwidth is similar to that with the number of interfaces. Note that the quantization rate per symbol decays inversely with bandwidth. When the operating bandwidth is lowered from W^*, the capacity is lowered because the reduction in power efficiency is more than the reduction in quantizer distortion. On the other hand, when the operating bandwidth is increased from W^*, the loss in capacity from increased quantizer distortion is more than the capacity gain from increased power efficiency.
The optimal bandwidth, W^*, can be found by numerical techniques. Figure 5 shows the plot of the capacity of our scheme and the upper bound (2) for $C_f = 200$ Mbps, $M_m\beta_m = 1$, $r = 2$ and $\frac{P}{N_0} = 100 \times 10^6$ sec^{-1}. The optimal bandwidth for this case is $W^* \sim 54.5$ Mhz.

5. CONCLUSION

In this work, we study a single-input, multiple-output FAWNA from a capacity view point. We propose a scheme and show that it has near-optimal performance when the fiber capacity is larger than the wireless capacity. We show that for given fiber capacity, there is an optimal operating wireless bandwidth and an optimal number of wireless-optical interfaces. We also show that an optimal rate allocation for a SIMO-FAWNA is one which ensures that each interface gets enough rate so that its noise is dominated by front end noise rather than quantizer distortion. Capacity is almost invariant to the way in which left over fiber capacity is allocated. Hence, large fiber capacity ensures robustness of SIMO-FAWNA capacity to interface rate allocation.
The wireless-optical interface has low complexity and does not require knowledge of the transmitter code book. The design also has extendability to FAWNAs with large number of transmitters and interfaces and offers adaptability to variable rates, changing channel conditions and node positions. Future work may consider FAWNAs with multiple transmitters and examine the performance of various multiple access schemes.

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