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Mixed signal based transmission in mixed layers for high throughput wireless network

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ABSTRACT

In a wireless network, one of the major problem is optimization. Optimization problem is finding the best path from all possible paths. This paper proposes a new architecture called Mixed Layer Design to avoid this problem. Even after providing faster transmission of data we are still facing a problem called throughput in wireless network. This problem is due to the interference of wireless signals. In a wireless network, the signal sent by a terminal will be received by all its neighbouring nodes. If a neighbour (except the destinations) is receiving data from some other terminals at the same time, the signals will collide, and the useful signal will be destroyed, which may result in transmission failure. To solve this problem we are proposing Mixed Signals to avoid the collision of signals. We show that intelligently mixing signals and layers increases network throughput and transmission time.

Introduction

In the last decade, multi-hop wireless networks, including wireless sensor networks(WSNs), wireless mesh networks (WMNs), mobile ad hoc networks(MANETs), vehicular ad hoc networks(VANETs), etc, have emerged as promising approaches to provide more convenient Internet access due to their extended cover range, easy deployment and low cost [1,2,5,7]. The success of communication network has largely been a result of adopting a layered architecture. With this architecture, its design and implementation is divided into simpler modules that are separately designed and implemented and then interconnected. A protocol stack typically has five layers, application, transport (TCP), network (IP), data link (include MAC) and physical layer. Each layer controls a subset of the decision variables, hides the complexity of the layer below and provides well-defined services to the layer above. Together, they allocate networked resources to provide a reliable and usually best-effort communication service to a large pool of competing users.

Our current theory integrates three functions— congestion control, routing and scheduling—in transport, network and link layers into a coherent framework. While the integration of all protocol components remain a big challenge, this framework is promising to be extended to provide a mathematical theory for network architecture, and allow us to systematically derive the layering structure of the various mechanisms of different protocol layers, their interfaces, and the control information that must cross these interfaces to achieve a certain performance and robustness. Broadcasting of data is a convenient way of one-to-many transmissions. Occasional data loss may occur due to channel impairments.

In a wireless network, signals sent by a terminal can reach all its neighbours, whereas a terminal may simultaneously receive the signals from all its nearby nodes. In traditional wireless networks, this collision of signals may cause transmission failure if no division technique is adopted. This will degrade the system performance, such as the packet loss rate and energy efficiency. Moreover, in distributed networks such as ad hoc and some sensor networks, the absence of control center will increase the opportunity of collision[8] and interference, which further reduces the transmission rate and brings about the inevitable hidden- and exposed-node problems. Wireless networks due to the broadcast nature of wireless channels, which results in mixing of signals [3] as nodes overhear transmissions from other nodes. However, most of the existing works directly extended the separate network and channel coding strategy from wired networks to the wireless realm [6]. A natural question would be whether such a separation is still optimal for wireless networks.

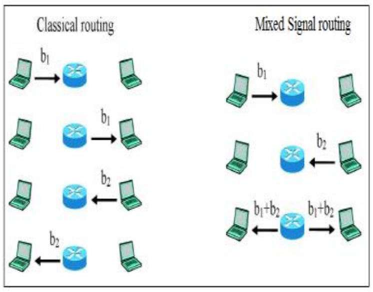

Figure 1: An example of decreasing time of mixed signals

In Figure 1 we show a simple example of using network coding to reduce the number of transmissions used to exchange two bits b1 and b2, using the linear combiner. With network coding, the first node can recover the bit b2 from the received bit b1+b2 and the known bit b1. Similarly, b1 can be recovered at the second node. Network coding can reduces the traffic without increasing delay.

Let suppose for a network that source node s emits K information packets x1, x2, ..., xK, each of length L symbols from a finite field GF(q) to N receivers t1, t2, ..., tN. For linear network coding, each node combines a number of received packets into one or several output packets:

$$y = \sum_{i=1}^{K} \alpha_i x_i$$

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where the summation is applied for every symbol position. For random linear network coding, the coefficients i of the linear combination are generates in a random manner, which assures with high probability a linear independence of the output packets from a node for a sufficiently large size q = 2m of the finite field GF(q), as it was proved in [4].

Optimization

In our abstraction, we represent a communication network with a set of nodes communicating with each other using some physical medium, e.g. optical fiber or air interface. A node represents a user, e.g. a stationary PC for IP networks or a cell-phone in cellular networks. The connections between nodes, so called (logical) links[9], act as pipes in which data flows. When a node desires to communicate with a distant node, it might be beneficial to use intermediate nodes, so-called relaying devices, which receive the signal from the source, reinforce it and forward it toward the destination. Relaying nodes may simply be placed to improve the connection.

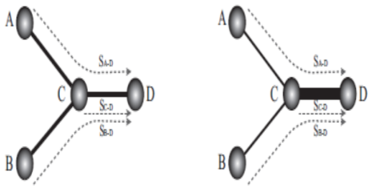

Figure 2: Four nodes (circles) communicate through three links (solid line) with controllable link capacities. The thickness of the lines corresponds to the capacity. The three leftmost nodes desire to send as much data as possible to the rightmost node. (a) When the network is not optimized, for instance allocating equal capacity to all links, the link to the right is a bottleneck. (b) Through cross-layer optimization, the link to the right is assigned more resources allowing more data to be transferred from nodes in the left side to the right side. The bottleneck link has been relieved.

Mixed Layer Design

In the last section, we have discussed the resource allocation in multihop wireless networks where the path for each network layer flow is given. However, as wireless spectrum is a scarce resource, it may be costly to maintain end-to-end paths, and congestion control based on end-to-end feedback may consume too much bandwidth in signalling. Moreover, most routing schemes for multihop networks select paths that minimize hop count; see, e.g., [11] [13]. This implicitly predefines a path for any source-destination pair, independent of the pattern of traffic demand and interference/contention among links. This may result in congestion at some region while other regions are underutilized. In order to achieve high end-to-end throughput and efficient resource allocation, the paths should not be decided exogenously but jointly optimized with congestion control and scheduling. Since the actual paths that will be used are not specified a priori, we will use multicommodity flow model for routing and model the resource allocation as a utility maximization problem with the constraints [2] and [5],

$$\max_{x,f} \quad \sum_s U_s(x_s)$$
$$\text{subject to} \quad x_i^k \le \sum_{j:(i,j)\in L} f_{i,j}^k - \sum_{j:(j,i)\in L} f_{j,i}^k,$$
$$f \in \Pi,$$

where

$i \in N,\ k \in D, i \ne k$, and $x_i^k = 0$ if $[i,k] \notin S \times D$.

Again, this problem is a special case of the system problem [7]–[9]. In the next subsection, we apply the algorithm [10]–[13] to obtain a distributed sub gradient algorithm for joint congestion control, routing and scheduling. This algorithm motivates a joint design where the source adjusts its sending rate according to the congestion price generated locally at the source node[10], and backpressure from the differential price of neighbouring nodes is used for optimal scheduling and routing.

Distributed Algorithm

Consider the Lagrangian of the problem (33)–(35) with respect to the rate constraint

$$L(p,x,f) = \sum_s U_s(x_s) - \sum_{i\in N, k\in D, i\ne k} p_i^k (x_i^k - \sum_{j:(i,j)\in L} f_{i,j}^k + \sum_{j:(j,i)\in L} f_{j,i}^k).$$

Interpret *pkl* as the congestion price at node *i* for the flows to destination *k*, we can use the algorithm (10)–(13) to solve the problem (33)–(35) and its dual.

Rate control: At time *t*, given congestion price *p*(*t*), the source *s* adjusts its sending rate *xs* according to the local congestion price at the source node.

$$x_s(p) = U_s'^{-1}(p_s),$$

Where

$$p_s = p_k^i \text{ for } s = [i,k] \in S \times D.$$

In contrast to traditional TCP congestion control where the source adjusts its sending rate according to the aggregate price along its path, in this algorithm the congestion price is generated locally at the source node.

Note that, since

$$\sum_{i,k} p_i^k \left(\sum_j f_{i,j}^k - \sum_j f_{j,i}^k \right) = \sum_{i,j,k} f_{i,j}^k \left(p_i^k - p_j^k \right),$$

the scheduling problem is equivalent to the following problem

$$\max_{f\in\Pi} \sum_{i,j} f_{i,j} \max_k \left(p_i^k - p_j^k \right).$$

This motivates the following joint scheduling and routing algorithm:

Scheduling: Each node *i* collects congestion price information from its neighbour *j*, finds destination *k*(*t*) such that

$$k(t) \in \arg\max_k (p_i^k(t) - p_j^k(t)),$$

and calculates differential price

$$w_{i,j}(t) = p_i^{k(t)}(t) - p_j^{k(t)}(t)$$

and passes this information to its neighbours. Allocate capacities e*fi*; *j*(*t*) over links (*i*; *j*) such that

$$\tilde{f}(t) \in \arg\max_{f\in\Pi} \sum_{(i,j)\in L} w_{i,j}(t) f_{i,j}.$$

If the network with time-varying channel is considered, each node monitors the channel state h(t) and allocates capacities efi; j(t) over links (i; j) such that

$$\tilde{f}(t) \in \arg\max_{f\in\Pi(h(t))} \sum_{(i,j)\in L} w_{i,j}(t) f_{i,j}.$$

Routing: Over link (i; j), send a number of bits for destination k(t) according to the rate determined by the scheduling.

The wi; j values represent the maximum differential congestion price of destination k flows between nodes i and j. The above algorithm uses backpressure to do optimal scheduling and find optimal routing[16]. Also note that the scheduling problem is solved by the following assignment,

$$f_{i,j}^{k}(t) = \begin{cases} \widetilde{f}_{i,j}(t) & \text{if } k = k(t), \\ 0 & \text{if } k \neq k(t). \end{cases}$$

Congestion price update: Each node *i* updates its price with respect to destination *k*, according to

$$p_i^k(t+1) = [p_i^k(t) + \gamma_t(x_i^k(p(t)) - (\sum_{j:(i,j)\in L} f_{i,j}^k(p(t)) - \sum_{j:(j,i)\in L} f_{j,i}^k(p(t))))]^+,$$

and passes the price *pki* to its neighbours. Note that *pki*(*t*) is interpreted as congestion price at the beginning of times lot *t*.

The above dual algorithm motivates a joint congestion control, routing and scheduling design where at the transport layer sources *s* individually adjust their rates according to the local congestion price at the source nodes, and nodes *i* individually update their prices according to [9], and at the network/link layer nodes *i* solve the scheduling [12] and route data flows accordingly. Also, note that the congestion control is not an end-to-end scheme. There is no need to maintain end-to-end paths and no communication overhead for congestion control.

A multicast example with source S and three receivers *R*1, *R*2, and *R*3 is shown in Figure 1. Note that each receiver can be disconnected from the source by removing two edges. Therefore, the min-cut from the source to each of the receivers is 2, and each receiver is connected to the source by a pair of edge-disjoint paths. The pair of paths for *R*1 are
S→A→D and S→B→D, for *R*2 are S→A→E and S→C→E, and for *R*3 are S→B→F and S→C→F. Note that the paths
S→B→D to *R*1 and S→B→F to *R*3 share the edge SB. When each of the receivers is the only one using the network, the source can transmit two independent unit rate bit streams simultaneously to the receiver through its two paths.

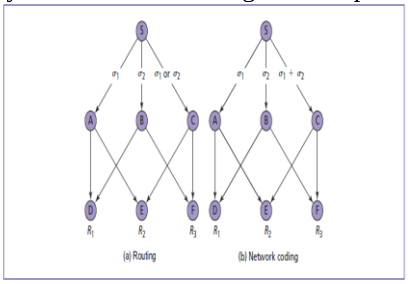

Figure 3

Network Coding for Some Specific Configurations: The example network is the one shown in Figure 3. We have already seen that routing alone cannot deliver a rate 2 multicast. However, the following simple network coding scheme can. Suppose that the source emits two bits s1 and s2 per unit time. We can transmit s1 along the path S→A→D, s2 along the path S→C→F, and s1 "s2 mod 2 along the paths S→B→D and S→B→F. Consequently, *R*1 will observe s1 and s1 " s2 mod 2; *R*2 will observe s1 and s2; and *R*3 will observe s2 and s1 " s2 mod 2. Therefore, all three receivers will obtain enough information to recover both s1 and s2.

Mixed Signal Transmission, Recovery Algorithm

For BPSK modulation, the signals of _x and _y can mathematically be written as

$Ax(t-D)\cos(\omega t+\gamma)$ and $By(t)\cos(\omega t)$.

respectively, where *x*(*t*), *y*(*t*) ∈ {1,−1}, and *γ* is the phase shift of the carrier of _x from that of _y. *A* and *B* are the signal amplitudes of _x and _y, respectively. Thus, the mixed signal of _x and _y at node *R*2 can be represented by

$$r(t) = By(t)\cos(\omega t) + Ax(t-D)\cos(\omega t+\gamma).$$

After demodulation and filtering, the sampled signal value of each symbol is

$$s_k = By_k + Ax_{k-D}\cos\gamma + n_k$$

where *k* is the sampling index, and *nk* is the additive Gaussian noise with variance *σ*2*n*= *N*0/2. For simplicity, let *yk* = *xk* = 0 for

$k \in [-L+1, 0) \cup [L, 2L)$.

We also assume that the carrier phase of _y and the local oscillator are ideally synchronized, and the impact of carrier-phase errors. Since the terminal *R*2 has received _x before, it can regenerate the sampling signal *xk* for 0 ≤ *k* < *L*. Then, one can compute the correlation between *{sk}* and the delayed signal *{xk−d}*, where *d* ∈ (−*L*,*L*) is an integer, to estimate *A* and *D*. That is

$$\begin{aligned} R(\vec{s},\vec{x},d) &= \sum_{k=-L}^{2L-1} s_k x_{k-d} \\ &= B\sum_{k=-L}^{2L-1} y_k x_{k-d} + \sum_{k=-L}^{2L-1} n_k x_{k-d} \\ &\quad + A'\sum_{k=-L}^{2L-1} x_{k-D}x_{k-d} \end{aligned}$$

where *A*_ = *A* cos *γ*. Through effective source coding and channel coding, *xk* and *yk* will take the value of *{*−1, 1*}* with equal probability and are independent of each other. Thus, we are satisfied that

$$E\left(\sum_{k=-L}^{2L-1} y_k x_{k-d}\right) = 0$$

$$E\left(\sum_{k=-L}^{2L-1} n_k x_{k-d}\right) = 0$$

$$E\left(\sum_{k=-L}^{2L-1} x_{k-D}x_{k-d}\right) = \begin{cases} L, & d = D \\ 0, & d \neq D. \end{cases}$$

According to the law of large numbers, if the frame length *L* is sufficiently large,

$\sum_{k=-L}^{2L-1} y_k x_{k-d}/L$ and $\sum_{k=-L}^{2L-1} n_k x_{k-d}/L$

will converge to 0 with very high probabilities. Moreover

$$A'\sum_{k=-L}^{2L-1} x_{k-D}x_{k-d}/L^{L\to\infty} \begin{cases} A', & d = D \\ 0, & d \neq D \end{cases}$$

is valid with a probability close to 1. Therefore, if one computes |*R*(_s, _x, *d*)| for each *d* ∈ (−*L*,*L*) and find out the maximum value, a reasonable estimation of *A* and *D* can be obtained by

$$\hat{A} = R(\vec{s},\vec{x},\hat{D})/L$$

Where

$\hat{D} = \arg\max_{-L<d<L} |R(\vec{s},\vec{x},d)|$.

By subtracting the estimated signal of _x from _s, _y can be recovered by

$$\hat{y}_k = s_k - \hat{A}x_{k-\hat{D}} \qquad (\max\{0, D\} \le k < \min\{L, L+D\}).$$

Note that if there are *h* frames of interference signals denoted by _x1, _x2, . . . , _x*h* instead of only one _x, all the interferences can be eliminated by repeating the aforementioned process for *h* times.

Benefits

Now that we have learned that how mixed signal transmission and how the mixed layer design is used for the high throughput, Using the mixed layer design we can transmit the data , congestion control, routing and scheduling very efficiently for multihop wireless networks[15]. As our design only requires nodes exchanging local information with their neighbours and does not need to maintain end-to-end paths, it has a very low communication overhead and can adapt to changing topologies such as those in mobile multihop networks.

With the using of mixed signal algorithm we are getting the benefits of high throughput. Throughput benefits of Mixed signals depend on the throughput measure and the traffic scenario[9]. Under our assumptions, there are examples (such as combination networks B(h,m) with *m* # *h*2), where with routing, we can only deliver information at rate 1 to some receivers, whereas with network coding, we can deliver information at rate *h* to all receivers. As we are using linear combiner in our paper to combine the signals so the complexity is O(n).

Conclusion

We have seen in this paper that, by formulating a general utility maximization problem for the network design, duality theory leads to a natural "vertical" decomposition into functional modules of various layers of the protocol stack and "horizontal" decomposition into distributed computation across various network nodes or links. As shown in Figure 4, our current theory integrates three functions—congestion control, routing and scheduling—in transport, network and link layers into a coherent framework, it helps us understand issues, clarify ideas, and suggests directions, leading to better and more robust designs for multihop wireless networks.

This framework—layering as dual decomposition in particular and layering as optimization decomposition[14]. We have proposed a mixed signal algorithm scheme based on the physical-layer network coding, which can eliminate the interference signal and recover the useful information from the mixed signal. By this scheme, a new scheduling strategy, which allows a certain kind of signal collision without division techniques, can be realized, and the throughput in wireless networks can greatly be increased.

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