Contrabass: Concurrent Transmissions without Coordination

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ABSTRACT
A PHY and MAC protocol for MIMO concurrent transmissions, called Contrabass, is presented. Concurrent transmissions, also referred to as multi-user MIMO, are simultaneous transmissions by multiple interfering nodes over the same carrier frequency. Concurrent transmissions technique has the potential of mitigating the overhead of MAC protocols by amortizing protocol overhead among multiple packets. However, existing proposals for concurrent transmissions could not achieve this as MIMO channel training and collision avoidance typically involve an expensive process of coordination and control message exchanges. This overhead has made MIMO concurrent transmission impractical and thus unused in real applications. Contrabass implements simultaneous channel training and optimal transmission control without any coordination. As a result, Contrabass achieves very high aggregate throughput, low delays and scalability even under dynamic environments and outperforms the existing MIMO protocols. This is the first practical implementation of MIMO-based concurrent transmissions. We implemented Contrabass in GNU radios and also in NS-2.

Categories and Subject Descriptors
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General Terms
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MIMO, IEEE 802.11n, Spatial multiplexing, Interference cancellation, Multi-user transmissions

An important attribute of MIMO (multiple input multiple output) based multi-antenna processing is the spatial multiplexing. The nodes can simultaneously exchange up to \( m \) wireless frames over the same carrier frequency when there are \( m \) antennas at the receivers.

Recently, IEEE has announced the standardization of 802.11n that utilizes the spatial multiplexing capability of MIMO. 802.11n is one form of the exclusive transmission protocols in that only one transmitter is allowed to transmit at a time, using all of its antennas. With the exclusive transmission, a single packet is transmitted at a higher data rate (i.e., \( m \) times a link rate of a single transceiver).

The problem with the exclusive transmissions is that the protocol overhead, such as channel training, ACK frame transmissions, idle slots and packet collisions, is constant regardless of the link layer data rate. This wasted portion of channel time largely prevents the performance improvement of the system. To mitigate the overhead, 802.11n performs a frame aggregation by merging multiple packets into a single large frame. But in many situations the aggregation is not possible due to the diverse traffic patterns and network topologies. Also, the large size of the frame often increases the chance of channel errors.

Concurrent transmissions, on the other hand, can naturally implement the overhead amortization as they permit multiple nodes to participate in the transmission at the same time. Since packets are available from multiple nodes, there are more opportunities for simultaneous transmissions. Also, it is possible to adjust the average number of concurrent transmissions such that the chance of successful packet transmission is maximized, while minimizing the collisions and the channel errors. See Sundaresan et al. [7] for more cases where concurrent transmissions perform better than exclusive transmissions.

There have been several proposals for the concurrent transmissions including [3, 6, 7]. Unfortunately, these protocols incur too much control overhead, diminishing the potential gains from the concurrent transmissions. The primary source of the overhead is the use of control messages such as RTS and CTS. The reason for the negotiation is twofold. First, the explicit channel training scheme, such as MMSE (minimum mean squared error), is known to be optimal but requires the dedicated channel training period for each transmitter and receiver pair. Unlike the exclusive transmissions, where only one node transmits and thus easily schedules the channel training, the concurrent transmissions require the negotiation between multiple transmitter and receiver pairs. Second, the transmitters should adjust the number of concurrent transmissions such that the total number does not exceed the number of antennas at the receivers.

Our goal is to design an efficient PHY/MAC protocol for concurrent transmissions that does not require any coordination. Contrabass does not introduce any control frame exchange and each node does not require any prior knowledge other than the MAC addresses of receivers.

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1. PROTOCOL DESIGN

Contrabass uses RLS (recursive least squares) based channel training [2]. With RLS, a receiver can train the channel filter even with the overlapped training sequences from multiple transmitters. The multiple transmitters can start transmissions without the scheduling of the channel training. RLS has never been used for concurrent channel training as it requires a longer training sequence than MMSE. However, as control messages are not used, the overhead due to the longer training sequence is easily compensated by the concurrent transmissions gain. RLS requires that the training sequence should be unique per any receiver.

There are two main challenges for coordination-free RLS-based concurrent transmissions. First, a receiver needs to identify and tune to an incoming training sequence to itself, among multiple overlapped signals. Second, the total number of concurrent transmissions must be kept less than but close to $m$.

To solve the first problem, a transmitter generates an RLS training sequence using the receiver’s ID (MAC address), circularly bit-shifts the training sequence to begin at a random index and embeds it into the preamble of the packet. The receiver then correlates the incoming signals with the shared training sequence, finds the synchronization point and trains the channel filter accordingly. It performs SIC (successive interference cancellation) [4] to cancel out the decoded signals and to further find other incoming training sequences and to further find other incoming training sequences and repeats the process from the start.

To solve the second problem, Contrabass adopts a $p$-persistent CSMA style MAC protocol and adjusts the transmission attempt probability during the runtime (Figure 1). The optimal transmission attempt probability that maximizes the chance of successful transmission is mathematically derived as follows:

$$
\tau_{opt} = \frac{1}{m(\frac{n-n}{m}) + 1},
$$

where $n$ is the number of transmitters within the interference range and $m$ is the number of antennas at the receiver. Note that $n$ is difficult to know in the real environment. Hence, we take a control-theoretical approach to match the observed contention level to one obtained from mathematically derived optimal result. The algorithm is highly adaptive to the level of contention and does not require any knowledge of $n$.

2. EVALUATION

We have implemented the PHY portion of Contrabass including RLS, RIC and SIC, in the GNU Radio platform[1] and conducted a proof of concept experiment. Our experiment indicates that Contrabass can successfully decode signals from concurrent transmissions using its PHY pro-

tocols. GNU radios do not permit an effective implementation of real-time carrier sensing [5]. To overcome this limitation of evaluation using GNU radio implementation, we implemented the entire protocol of Contrabass is implemented in NS-2 for evaluation under diverse network topologies and conditions. Contrabass and several existing concurrent transmission protocols, and IEEE 802.11n are tested under diverse network and traffic conditions. Figure 2 shows the simulation result when the 100 nodes are exchanging FTP traffic while total number of sessions is varied. Compared to IEEE 802.11 with frame aggregation, it achieves about 60 to 70% performance improvement under high load. We also verified that Contrabass shows high scalability under other diverse traffic load conditions such as Web traffic and VoIP traffic in terms of throughput and delays, and greatly outperforms the existing concurrent transmission protocols. The most salient key advantage of Contrabass is its amenability to practical implementation.

3. REFERENCES


