Optimize the Capacity of WiMAX Networks with Bandwidth Recycling

The Aeronautical Mobile Airport Communication System (AeroMACS) network offers a quantum improvement in communications to support the efficient and safe operation of aircraft, vehicles and personnel on the ground. The network, based on the 802.16 WiMAX standard, is broadband and is capable of supporting a wide variety of data communications. The ability to implement network security and quality of service (QoS) provide a way to replace outdated systems and practices that cannot keep pace with increasing operational requirements. Ground communication services delivered through the AeroMACS network will improve safety and efficiency for airport ground operations worldwide.

The network architecture must reserve sufficient capacity to service critical applications with a high quality of service. Guarantees of service include defined bandwidth and latency, along with a high rate of successful packet delivery. Less critical communications necessarily share remaining network capacity based on lower levels of guarantee. Not all communications require a guarantee for a constant bit rate, minimal latency or low percentage of dropped packets. Network architecture will determine how well the system can support all users with acceptable levels of service.

The AeroMACS network has far greater capacity compared to the various legacy systems that it will eventually replace. This capacity increase is certainly welcome, but as we have seen with all other wireless systems, demand for bandwidth grows very quickly. If demand grows faster than capacity, network performance will degrade. High QoS services will take a greater percentage of network capacity and other classes of service will start to suffer performance degradation and delay. Increased demand for bandwidth must be balanced by increased network capacity if level of service is to be maintained. There are many methods used to increase wireless network capacity. Following is a brief listing of five such methods, along with a description of associated drivers of cost or difficulty.

The first method is to obtain more spectrum. Capacity of a network is directly proportional to the operating bandwidth. With all other factors unchanged, doubling capacity means doubling the bandwidth. Spectrum, being a finite and scarce resource, is carefully allocated by regulatory agencies. Obtaining additional spectrum, if it is available at all, is a very costly proposition.

The second method is to increase transmit power. Capacity of a link is a function of signal-to-noise plus interference ratio (S/N+I). More power equates to increased signal. There are practical limitations to increasing transmit power. The process of increasing power may also cause the system noise and interference to increase. Thus, total signal-to-noise plus interference may only increase marginally. There is a cost to the transmitter in terms of power consumption, heat, and size. There is the potential for the higher power transmission to cause interference to other systems. The emission mask for transmitters must meet regulatory requirements, which will limit or even prevent an increase in transmit power. More power can be a solution in some cases, but comes with a complex set of constraints.

The third method is to reduce system interference. Reducing interference necessarily improves the signal-to-noise plus interference ratio. Base station coverage can be divided into sectors by using directional antennas. This provides spatial isolation, reducing interference from adjacent cells and sectors, and enabling increased frequency reuse. More sectors require more antennas and radios per base station. Each of the antennas is larger, and the base station equipment is more complex. Sectorization is routinely implemented in cellular networks to maximize frequency reuse.

The fourth method is to employ a more efficient modulation and coding scheme. More complex modulation schemes encode more bits for each symbol transmitted, with a corresponding increase in data rate. Coding schemes incorporate parity bits for error detection and correction. A scheme with fewer parity bits uses a higher percentage of the data stream for the applications. The combination of modulation and coding is dependent on the system S/N+I. Current modulation and coding schemes are very efficient, pushing up against the theoretical limit of channel capacity. Adaptive schemes will measure channel quality and allow the data rate to increase or decrease as channel conditions change. This approach makes the most of available spectrum, but is still dependent on the system S/N+I.

The fifth method is to increase density of base stations. Each base station serves a smaller area. Network capacity increases through greater frequency reuse over the area served. A wireless network achieves wide area coverage with macrocells. Additional coverage is provided to hotspots with dense local user traffic by supplemental microcells and picocells. There are associated costs due to purchase, installation, operation and maintenance of additional network equipment.

The above methods tend to address the limitations of the physical signal, defined by bandwidth, power, noise and interference. The associated solutions tend toward adding something to the system to increase capacity. Obtaining more bandwidth. Transmitting more power. Installing more equipment to reduce interference. An alternative to increasing network capacity through physical means is making better use of existing network capacity with a method called Bandwidth Recycling.

Bandwidth Recycling is a method of scheduling packet delivery. The method recycles Uplink (mobile to base station) bandwidth for user applications that are accessing non-real-time applications. Constant Bit Rate services are not affected, so the reservation system maintains the same QoS guarantees. Using this method, network throughput improves by up to 40%, with a consequent reduction in network latency. This method works when the need is greatest, as it becomes more effective when network congestion increases.

The network defines a connection for each user application with an assigned connection ID (CID), and with an associated bandwidth and QoS reservation. The assigned bandwidth is based on the user terminal Bandwidth Request (BR). Some applications make full use of the reservation, while other applications do not. Bandwidth Recycling is a method of assigning an alternate user or application to use network capacity that would normally be wasted. Think of a reservation as a priority assigned parking spot. The person uses it on a regular basis, and no one else can use the spot. When the person goes on vacation for two weeks, the spot can sit unused, effectively a wasted resource. Alternately, the person can offer to let a friend use the spot for two weeks. When the owner of the spot returns from vacation, they still have the exclusive right to use the spot. They have not given up their guarantee of service, just freed it up for someone else when they were not using it.

Packet networks employ methods to schedule delivery of packets for the users and applications. A priority-based scheduling algorithm (PSA) implements multiple QoS classes. Packets are queued and served according to priority. All services run smoothly when the network is lightly or moderately loaded.

As traffic increases, lower level services will suffer performance degradation. Variations of the scheduling algorithm apply a weight to each QoS and enforce fairness so that lower level services do not completely starve. These methods manage the use of available bandwidth and attempt to provide the best service to all customers. However, these methods do not alleviate problems associated with congestion or unused bandwidth. Bandwidth Recycling addresses both, and can be implemented within the 802.16 protocol.

A Base Station (BS) serves a population of Subscriber Stations (SS). For each Subscriber Station, there is another Subscriber Station that is designated as a Complementary Station (CS). Subscriber Stations are assigned bandwidth for transmission by the Base Station. If the payload is less than the assigned bandwidth, network capacity is unused. Bandwidth Recycling incorporates scheduling algorithms that allow the Base Station to maintain a list of Complementary Stations, known as a Complementary List (CL). Messaging that is compatible with WiMAX protocols enable the Subscriber Station to send a Release Message (RM) during a frame when additional bandwidth is available. When the Complementary Station has packets that are ready to transmit and hears the Release Message, it immediately makes use of the remaining transmission slot.

Figure 1 is a representation of the Uplink transmission frame. The Transmitting Station uses the first portion of the frame. When it has no more data to transmit, it sends a Stuff Byte Value (SBV) to the Base Station, indicating that the transmission has ended. The Transmitting Station then sends the Releasing Message (RM). When the Complementary Station hears the RM, it then transmits data on the remaining portion of the frame. The protocol is illustrated in Figure 2.

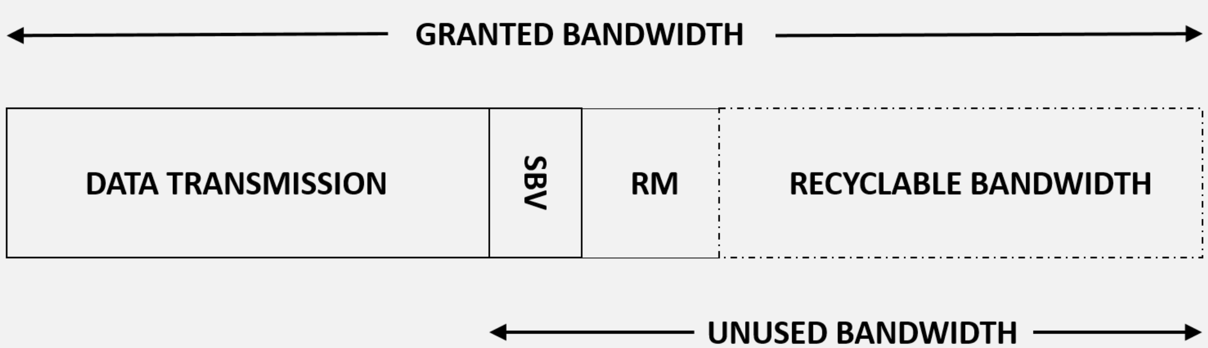

Figure 1. Uplink Transmission Frame

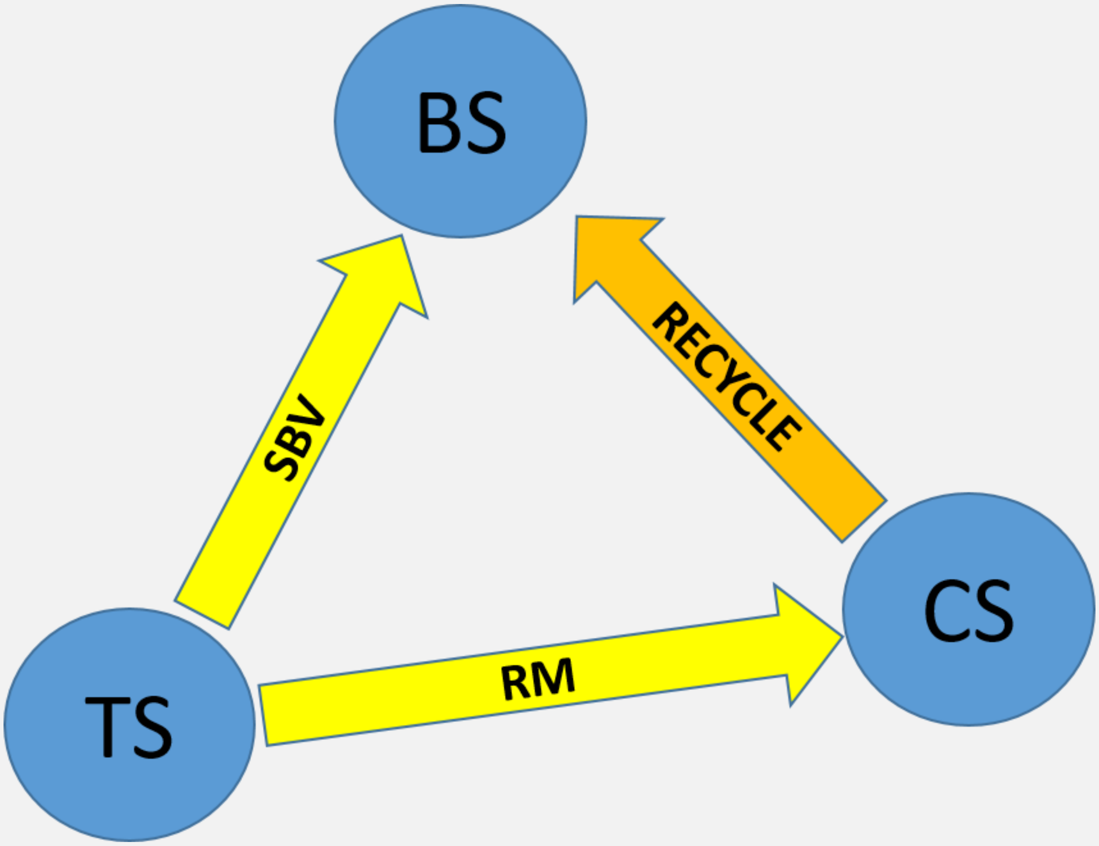

Figure 2. Bandwidth Recycling Protocol

Three conditions must be met to allow the Complementary Station to recycle the unused bandwidth. First, the Complementary Station must receive the Release Message. Second, the Complementary Station must be scheduled on the Complementary List. Third, the Complementary Station must have data to recycle on the unused bandwidth. Bandwidth Recycling implements a set of algorithms to address these conditions.

If a Complementary Station does not have data to recycle after it receives a Release Message, the available bandwidth is not recycled. This condition is addressed by an algorithm called Rejected Bandwidth Requests First Algorithm (RBRFA). Complementary Stations scheduled in the Complementary List had placed a Bandwidth Request in the previous frame, and had been rejected. Thus, the scheduled Complementary Station has data to send. Note that on lightly loaded networks, it is not likely that Subscriber Stations have had Bandwidth Requests rejected. This explains why the algorithm becomes more effective as congestion increases.

If a Complementary Station cannot hear the Release Message from a Transmitting Station (TS), it will not be able to transmit on the available bandwidth. The History-Based Scheduling Algorithm (HBA) alleviates this condition. Each time a Complementary Station receives a Release Message it transmits data in the available bandwidth. If the Complementary Station does not have user data to transmit, it pads the payload and transmits. If the Base Station does not receive a transmission from the Complementary Station after a Release Message, it determines that the Complementary Station did not receive the

Release Message. Over time, the Base Station builds a Black List (BL) of Complementary Stations that cannot receive the Release Message from associated Subscriber Stations. The Black List allows the Base Station to schedule Complementary Stations that have a high probability of receiving the Release Message from the associated Subscriber Station.

The RBRFA increases the probability that a Complementary Station has data to transmit when it receives a Release Message. The HBA increases the probability that a Complementary Station can hear the Release Message from its associated Subscriber Station. To maximize the effectiveness of Bandwidth Recycling, a Hybrid Scheduling Algorithm (HSA) combines both RBRFA and HBA. The HSA has shown improvements of over 40% in throughput on congested WiMAX networks. As an associated benefit of throughput improvement, network delay is also reduced. The algorithm does not change existing bandwidth reservations, resulting in no impact on QoS guarantees.

Consider a wireless network that has 60 MHz of bandwidth and is experiencing performance degradation due to congestion. One way of increasing capacity by 40% is to obtain an additional 24 MHz of bandwidth. An alternate way is to implement Bandwidth Recycling. More information about Bandwidth Recycling is available at: http://isurftech.technologypublisher.com/technology/19267.

About the author

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