Measuring the Capacity of IEEE 802.11 WLAN Networks

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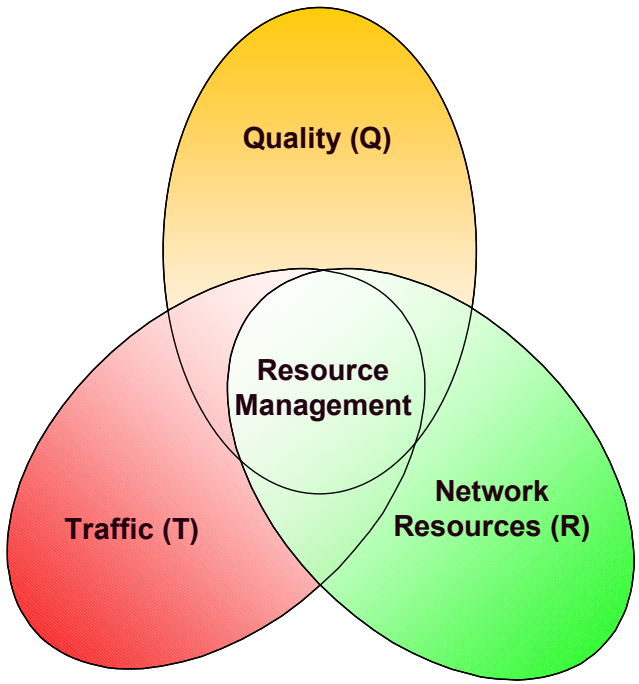
Overview

- Traffic Engineering and Radio Resource Management
- Review of 802.11 MAC Operation
- MAC Bandwidth Components
- MAC Operating Plane
- Measuring the Capacity
- Posssible RRM Scheme
- Summary

Traffic Engineering

- Ensuring predictable network performance.
- Many traffic engineering techniques available.
- Resource management-main issues:
  - Monitoring network resource usage.
  - Allocating network resources on basis of need and relative priorities.
- Important for QoS provisioning.

Radio Resource Management



Radio Resource Management

- Fixed spectrum allocation available.
- Engineering options:
  - Modulation scheme employed (L1/PHY).
  - Medium access scheme employed (L2/MAC).
- Multiple access schemes:
  - Monitoring individual user usage.
  - Estimating the available capacity.

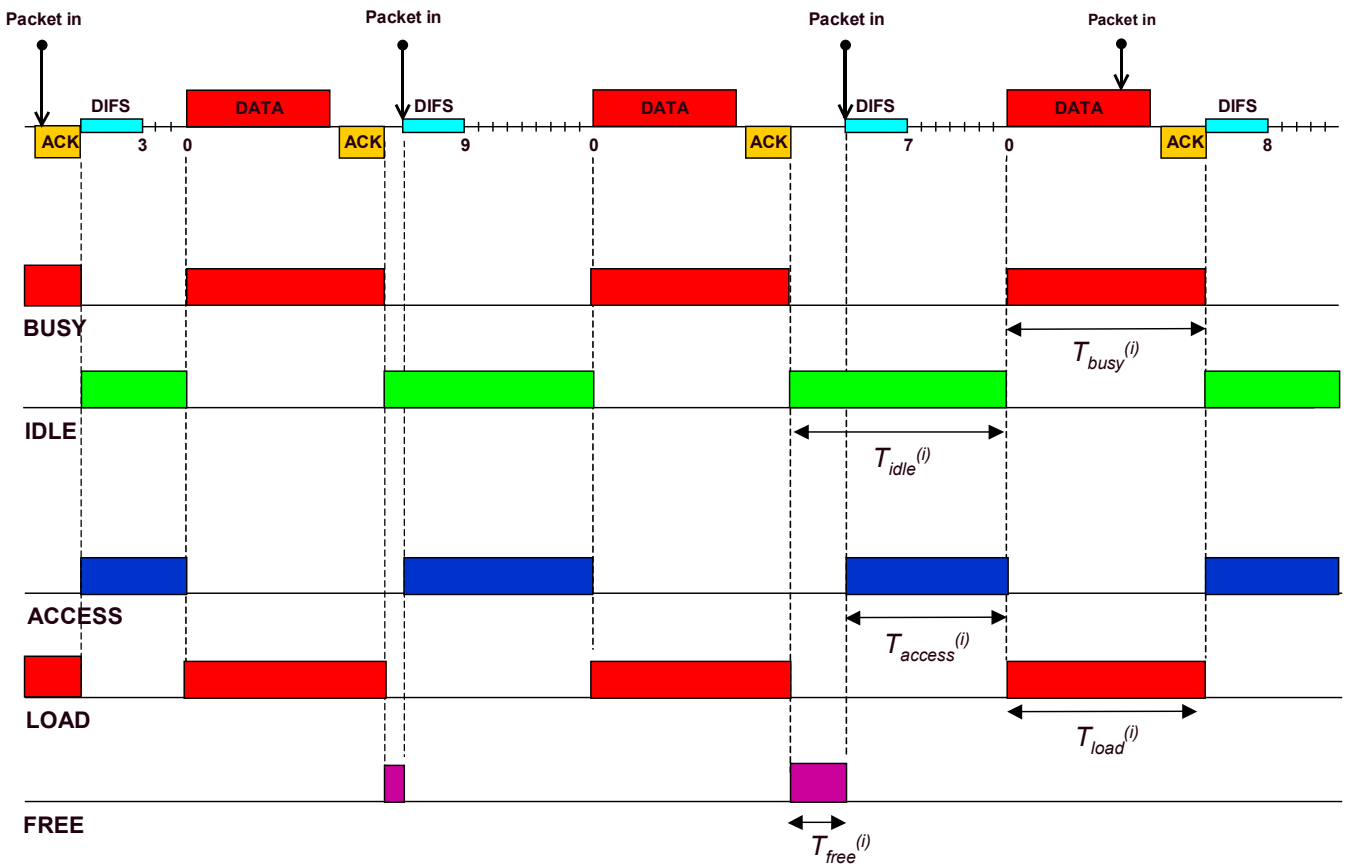
Features of the 802.11 MAC

- Shared medium.
- Access to the medium mediated through the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) mechanism.
- Contention-based random access.
- “Fair Protocol” – all users enjoy same probability of accessing the medium.

Problems with 802.11 MAC

- Although users share access opportunities equally, they do not share the bandwidth equally.
- Capacity of WLAN is traffic dependent.
- User performances are coupled.
- Greedy users can severely degrade overall performance.
- Cannot differentiate between users in terms of their access priorities (still waiting for 802.11e).

Time Intervals on Medium



Busy and Idle Intervals

- Alternating *busy* and *idle* intervals on the wireless medium.
- *Busy* intervals correspond to the transmission of wireless frames.
- *Idle* intervals used by STAs to win access opportunities for their loads.
- Unused idle intervals correspond to idle intervals not utilised to win access opportunities.

Busy and Idle Intervals

- *Busy* intervals correspond to the wireless medium being seized by a single STA (apart from during collisions).
- All other STAs must stop and defer to the busy medium.
- *Idle* intervals are shared by all STAs wishing to access the medium:
  - Wait for DIFS
  - Decrement its backoff timer every T_{slot} secs.

CSMA/CA and Idle Intervals

- CSMA/CA mechanism uses the idle intervals to coordinate access to the medium.
- STAs utilise the idle intervals to win access opportunities for its traffic load.
- Depending on the overall network load, a STA may undergo several cycles of deferring and decrementing before backoff timer reaches zero.
- Clearly there is a “cost” in terms of the availability of idle intervals in order to access the medium.

Saturation and Unused Idle Intervals

- Availability of idle intervals imposes an upper limit on the maximum transmission rate.
- At saturation, the availability of idle intervals just balances the access requirement.
- Unused idle intervals constitute a reservoir of "free" intervals, i.e. spare capacity.
- Different STAs will experience different amounts of free idle intervals and hence different capacities.
- Suggest that these "free" intervals may serve to give an indication of the QoS.

Coupling Between STAs

- STAs are directly coupled through the busy intervals comprising the sum of the load intervals of all STAs as these reduce the availability of idle intervals.
- Indirectly coupled through increased number of deferrals which increases the access requirement.

BW_{busy} and BW_{idle}

Busy and idle times are summed

$$T_{busy} = \sum_i T_{busy}^{(i)}$$

$$T_{idle} = \sum_i T_{idle}^{(i)}$$

Normalise and convert to line rate (e.g. line rate = 11 Mbps for 802.11b)

$$BW_{busy} = \frac{T_{busy}}{T_{busy} + T_{idle}} \times Line\_Rate$$

$$BW_{idle} = \frac{T_{idle}}{T_{busy} + T_{idle}} \times Line\_Rate$$

where $BW_{busy} + BW_{idle} = Line\_Rate$

BW_{load}, BW_{access}, and BW_{free}

- By identifying the sender of the wireless frame, possible to determine:
- BW_{load} associated with the transport of the STA's load.
- BW_{access} associated with winning of transmission opportunities for the STA.
- BW_{free} associated with the spare capacity available to the STA.

BW_{load}, BW_{access}, and BW_{free}

For a STA k, measure the load time intervals

$$T_{load}(k) = \sum_i T_{load}^{(i)}(k)$$

Normalise and convert to line rate

$$BW_{load}(k) = \frac{T_{load}(k)}{T_{busy} + T_{idle}} \times Line\_Rate$$

$$BW_{busy} = \sum_k BW_{load}(k) - BW_{collisions}$$

$$BW_{access}(k) + BW_{free}(k) = BW_{idle}$$ for any STA k

WLAN Resource Usage

Set of coupled equations serve to describe WLAN resource usage

$$BW_{busy} + BW_{idle} = Line\_Rate$$

$$BW_{busy} = \sum_{k} BW_{load}(k) - BW_{collisions}$$

$$BW_{access}(k) + BW_{free}(k) = BW_{idle}$$

for any STA k

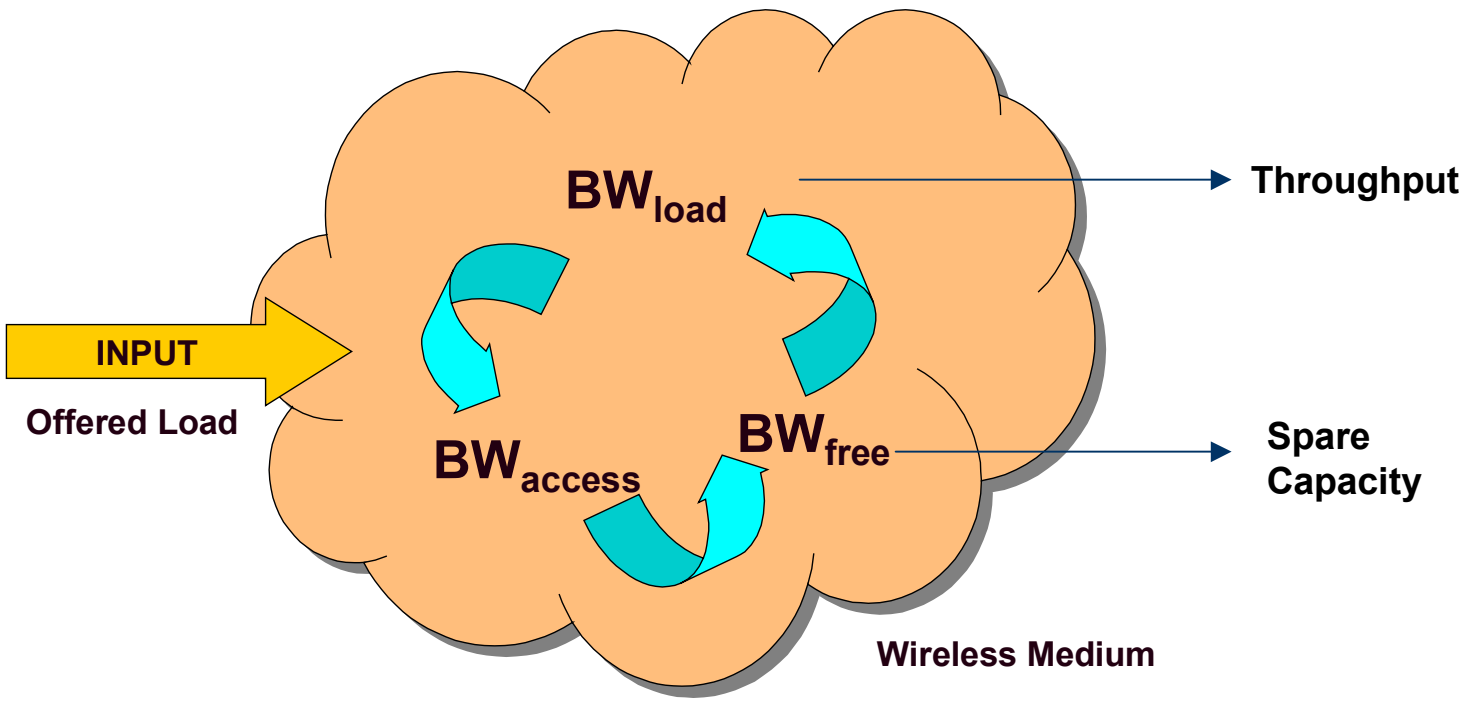
$$= Line\_Rate - BW_{busy}$$

$$= Line\_Rate - \sum_{i} BW_{load}(i) + BW_{collisions}$$

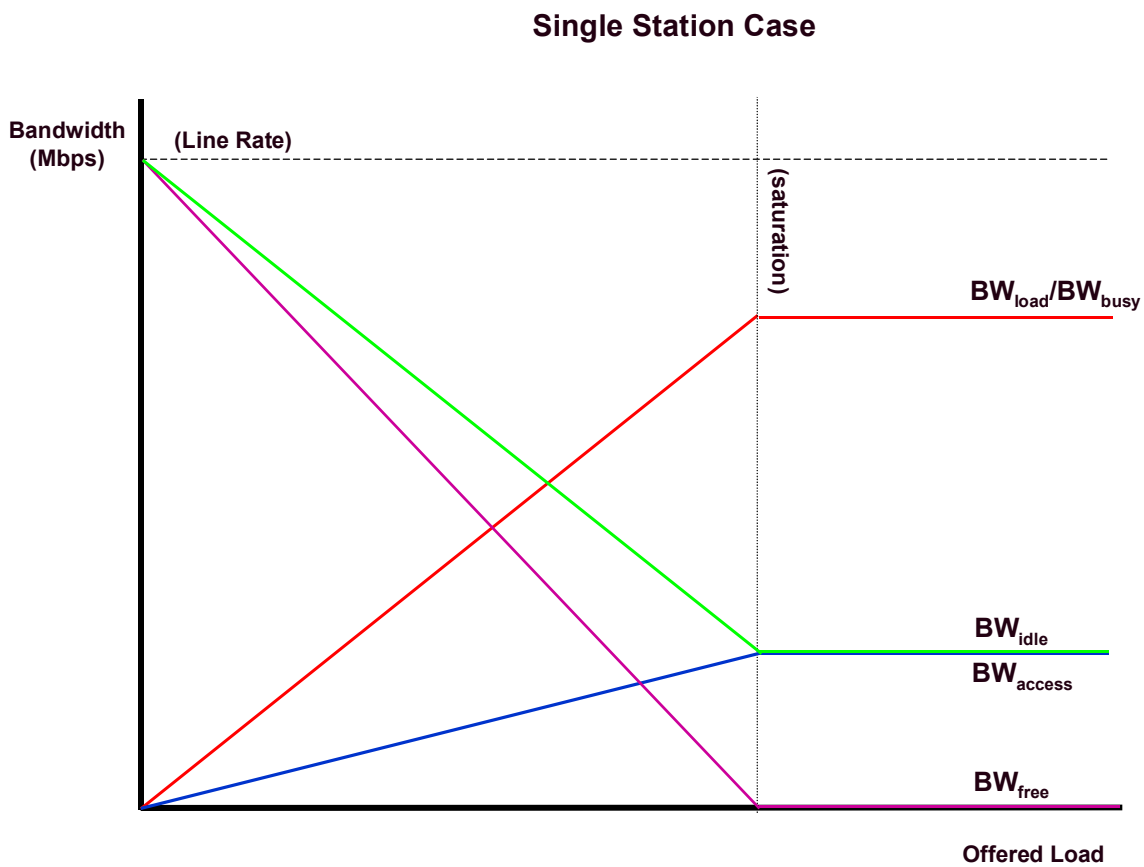
MAC BW Components

- Associated with the WLAN medium:
  - BW_{busy}
  - BW_{idle}
- Associated with each STA in the WLAN:
  - BW_{load}
  - BW_{access}
  - BW_{free}

MAC Bandwidth Components



Use of MAC Bandwidth Components



Increasing offered load to saturation where

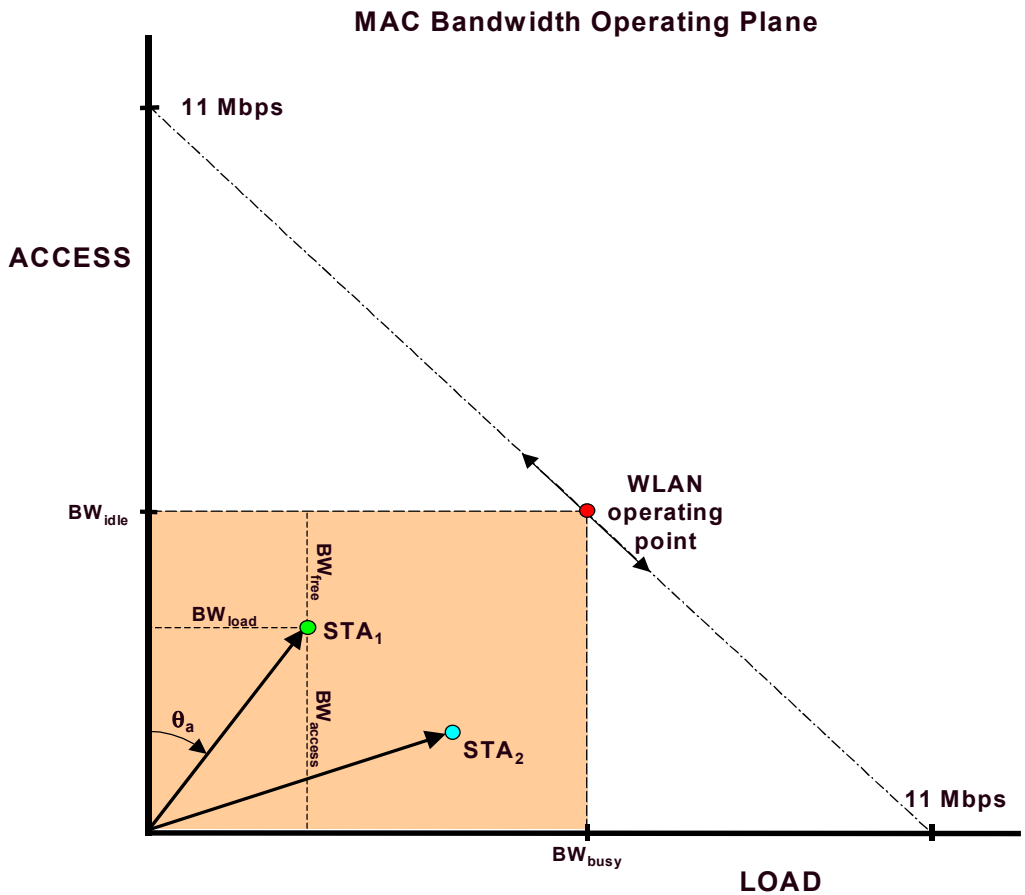
$$BW_{access} = BW_{idle}$$

$$BW_{free} = 0$$

MAC BW Operating Plane

- Extension of the MAC bandwidth components description.
- Establish an *operating plane* with axes comprising BW_{load} and BW_{access}.
- Individual STA operation can be characterised in terms of its "position" given by the coordinates (BW_{load}, BW_{access}) within this plane.
- Interaction between STAs can be visualised in terms of the impact on STA trajectories.

MAC Bandwidth Operating Plane



Access Efficiency

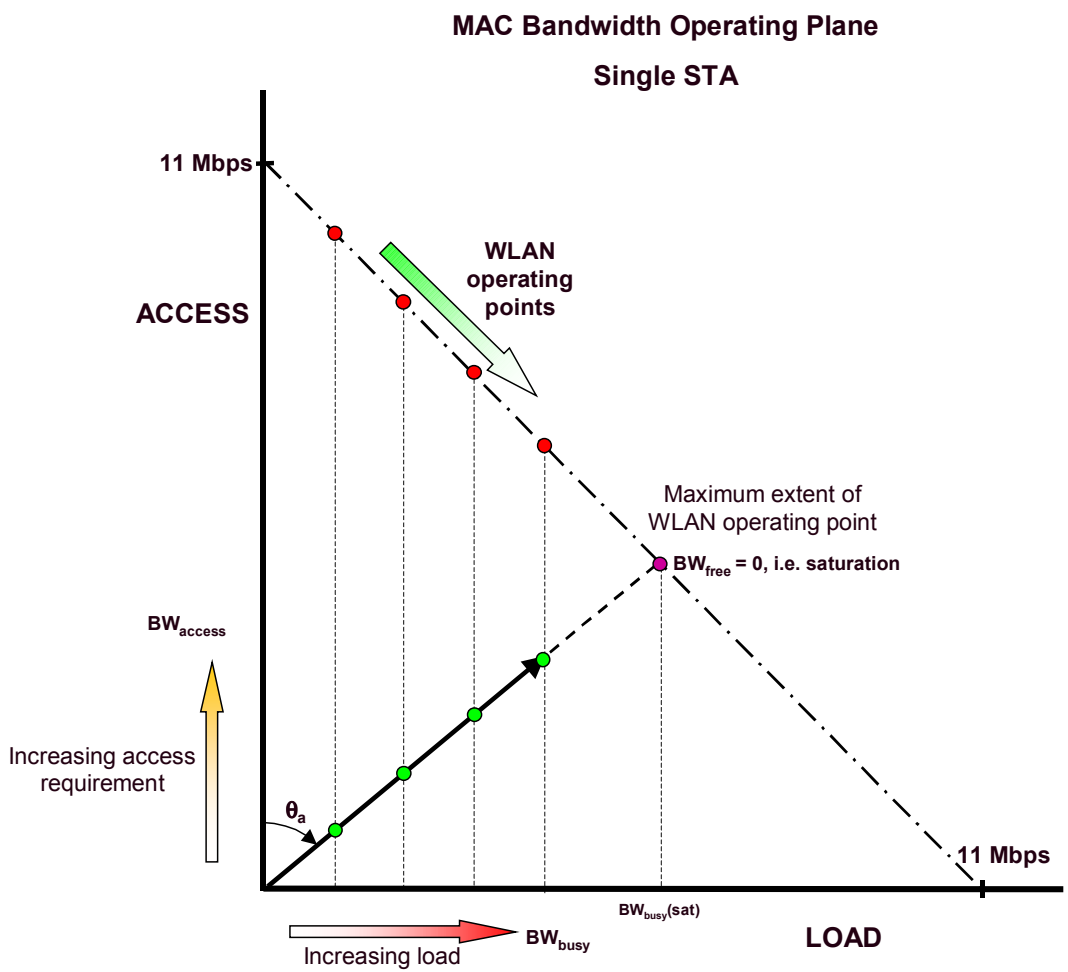
- Possible to indicate how efficiently a STA is utilising the medium.
- Define an access efficiency η_a as follows:

$$\eta_a = \frac{BW_{load}}{BW_{access}}$$

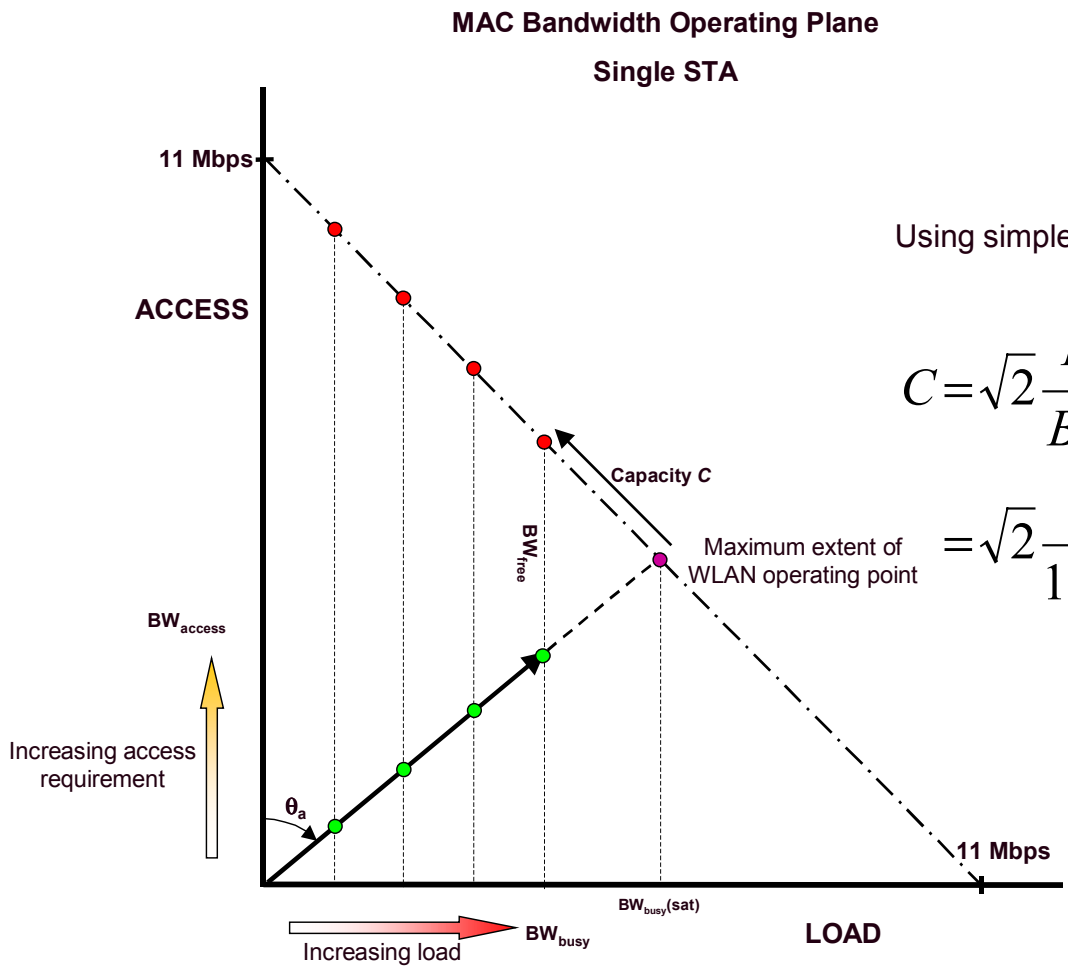
- In terms of the operating plane, define an efficiency angle θ_a

$$\theta_a = \tan^{-1} \eta_a$$

Increasing the Offered Load



Available Capacity

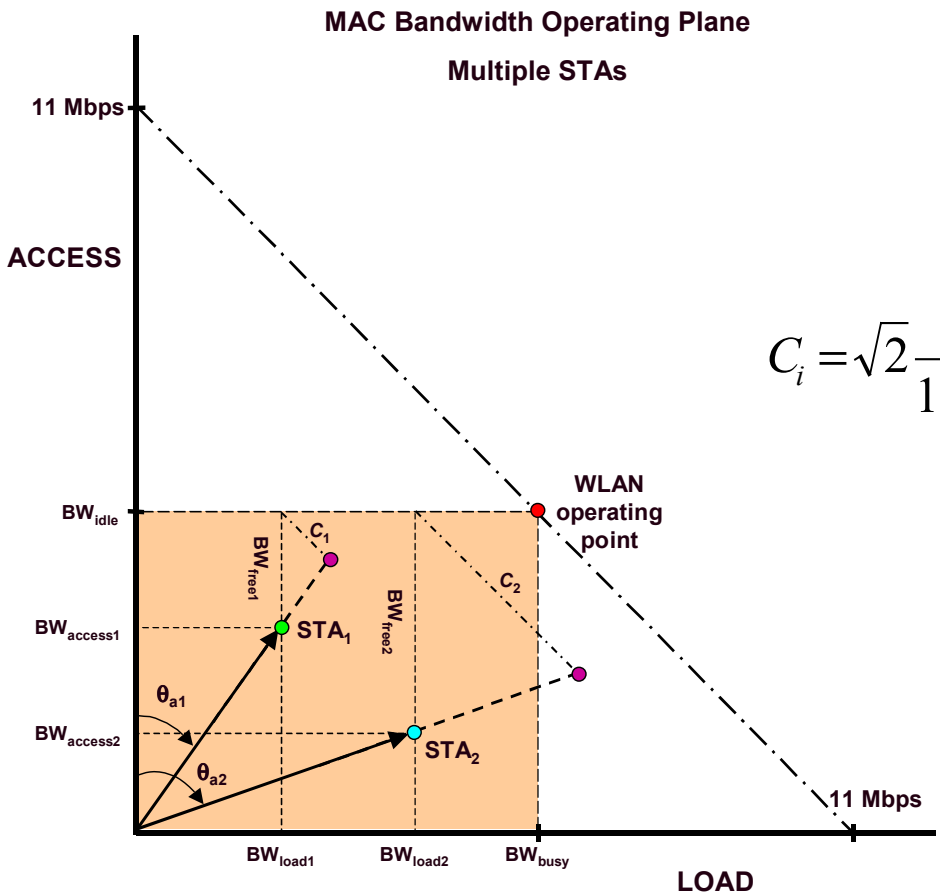


Using simple geometry

$$C = \sqrt{2}\frac{BW_{load} \times BW_{free}}{BW_{access} + BW_{load}}$$

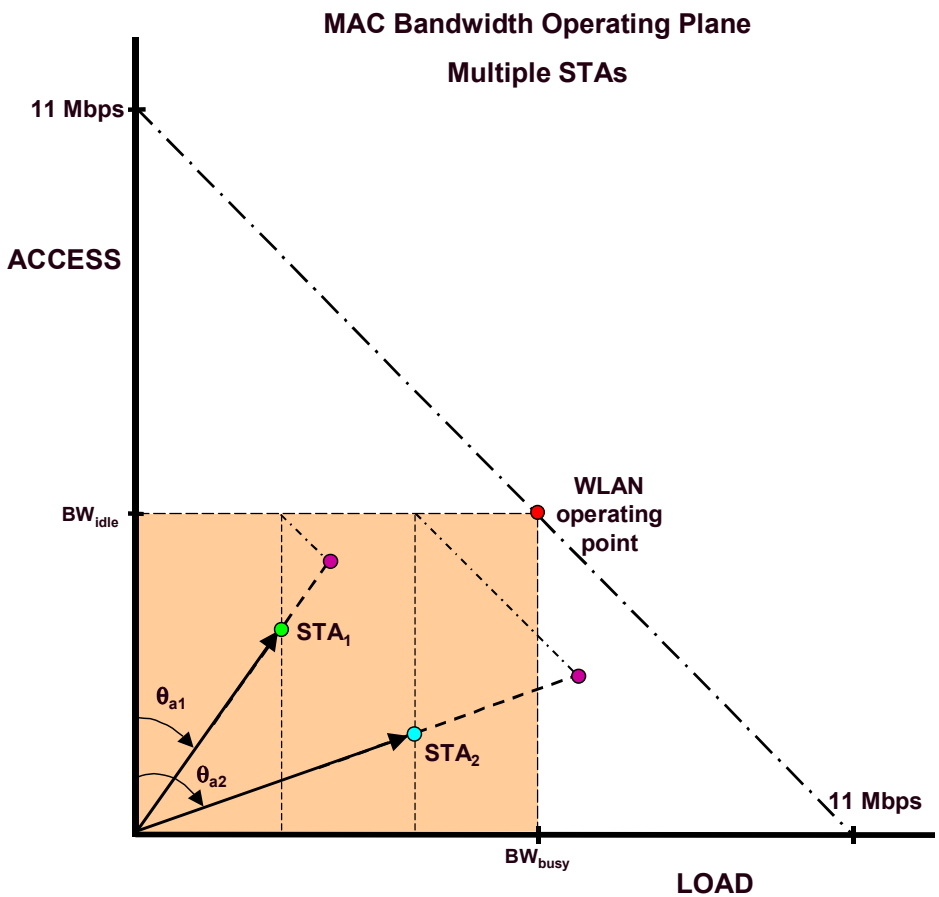
$$= \sqrt{2}\frac{\eta_a}{1+\eta_a} BW_{free}$$

Comparing Capacities

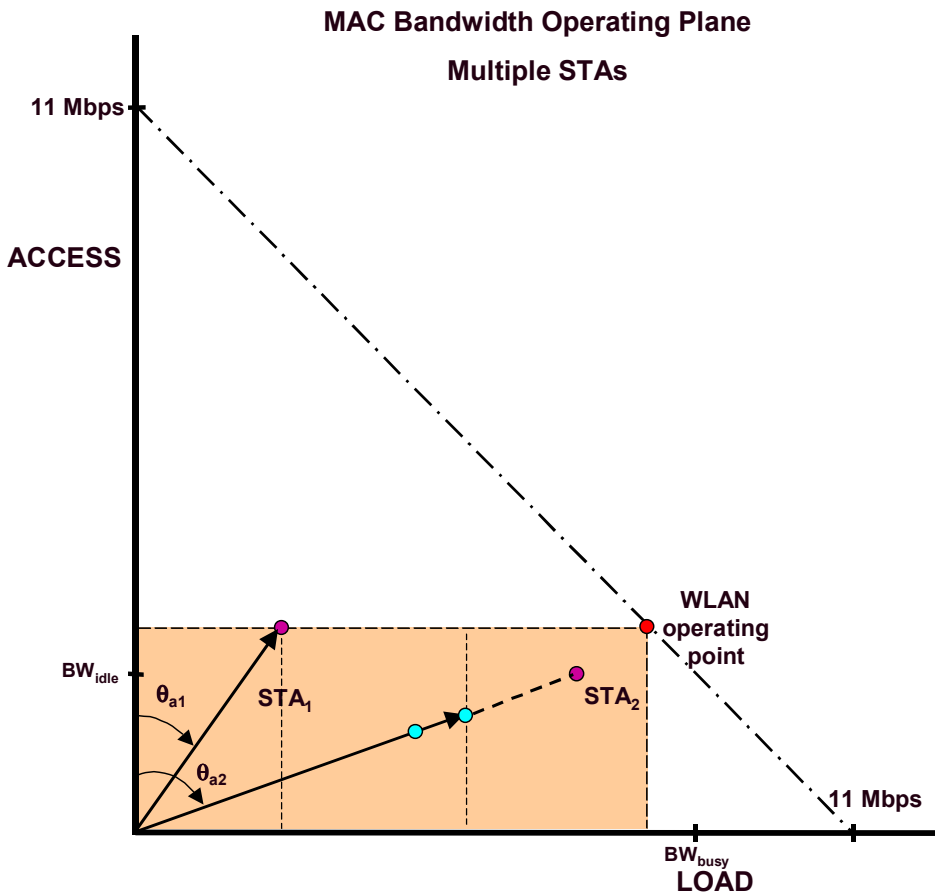


$$C_i = \sqrt{2}\frac{\eta_a(i)}{1+\eta_a(i)} BW_{free}(i)$$

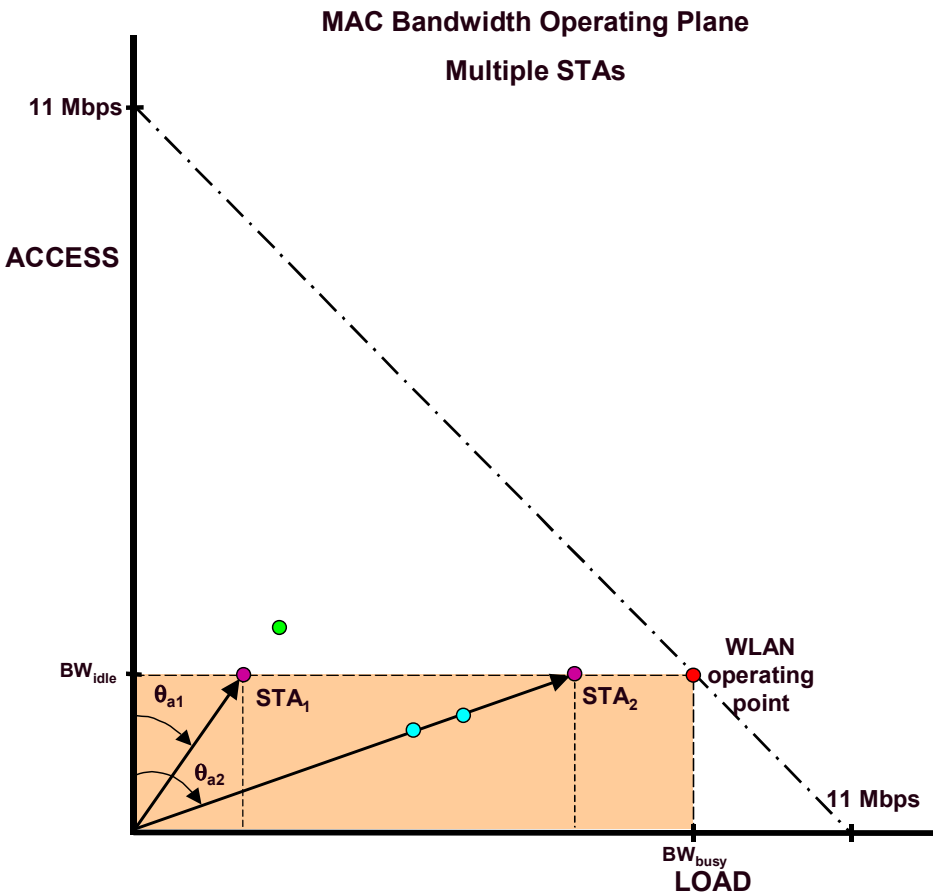
Increasing STA_2's Load (1)



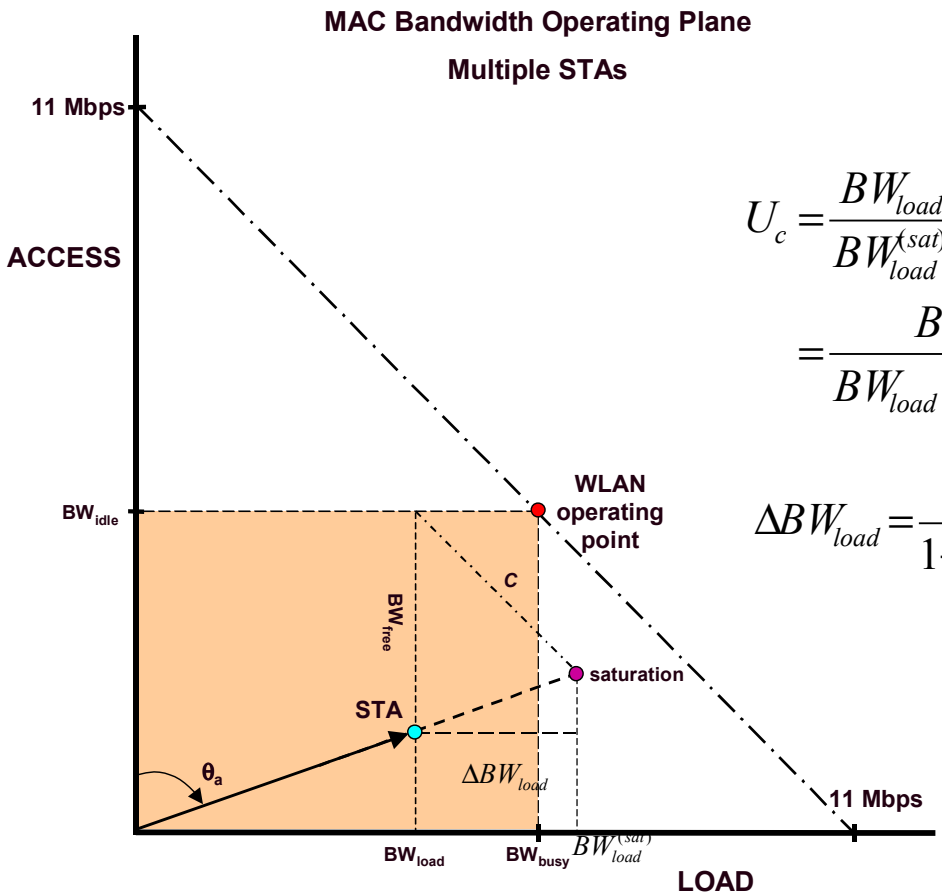
Increasing STA_2's Load (2)



Increasing STA_2's Load (3)



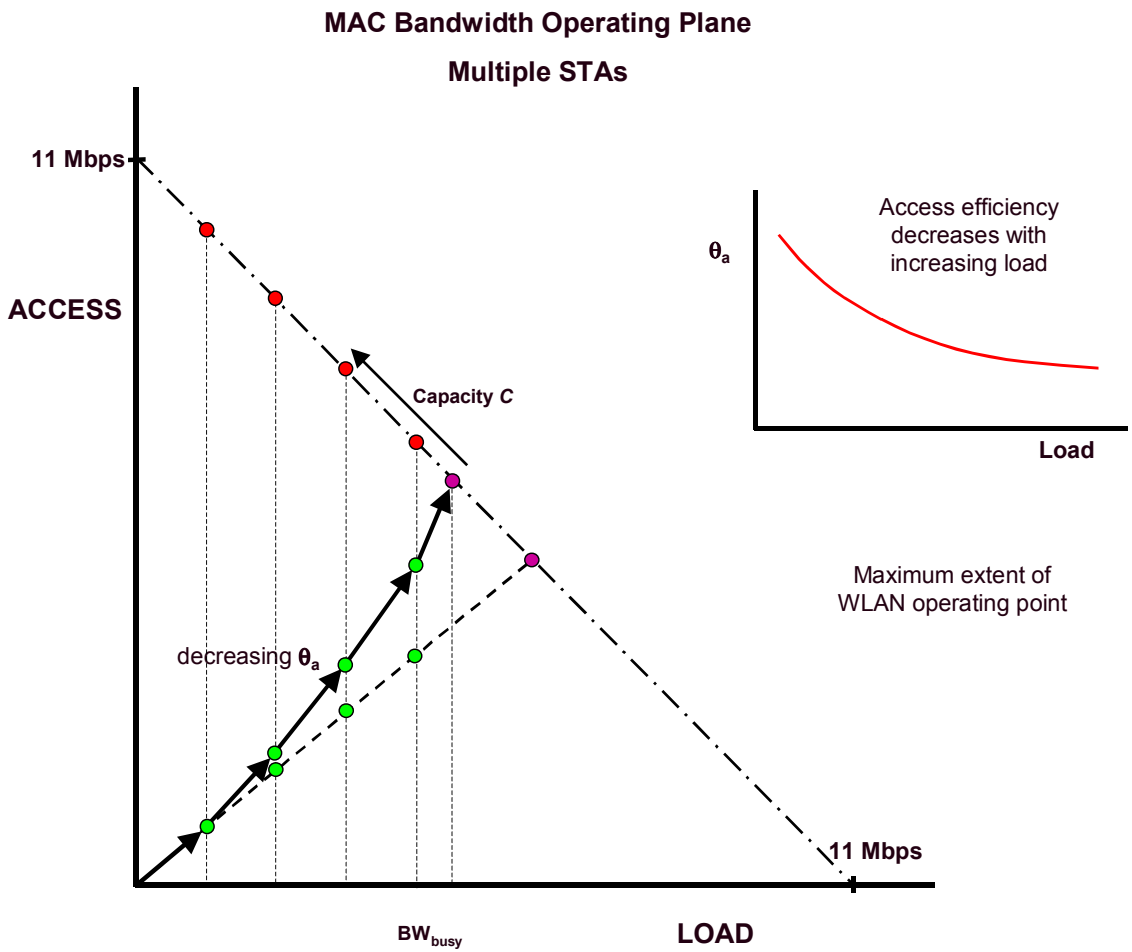
Utilisation of Available Capacity (U_c)



$$U_c = \frac{BW_{load}}{BW_{load}^{(sat)}} = \frac{BW_{load}}{BW_{load} + \Delta BW_{load}}$$

$$\Delta BW_{load} = \frac{\eta_a(i)}{1+\eta_a(i)} BW_{free}(i)$$

θ_a is load dependent



802.11e Parameters and Possible RRM Scheme

- The *AIFSN* and CW_{min} parameters can be used to control the access efficiency.
- Allows for differentiation between STAs in terms of their access efficiencies.
- Possible RRM scheme:
  - Low priority STAs assigned low access efficiencies (i.e. make it expensive to access the medium for their loads).
  - High priority STAs assigned high access efficiencies (i.e. make it cheap to access the medium for their loads).

Summary

- Review of 802.11 MAC operation.
- MAC bandwidth components.
- MAC operating plane.
- Measuring the available capacity C.
- Utilisation of available capacity U_c
- 802.11e operation and possible RRM scheme.

Thank You and Questions