Test Resource Management Center (TRMC)

National Spectrum Consortium (NSC) / Spectrum Access R&D Program

Test Range Spectrum Management with LTE-A

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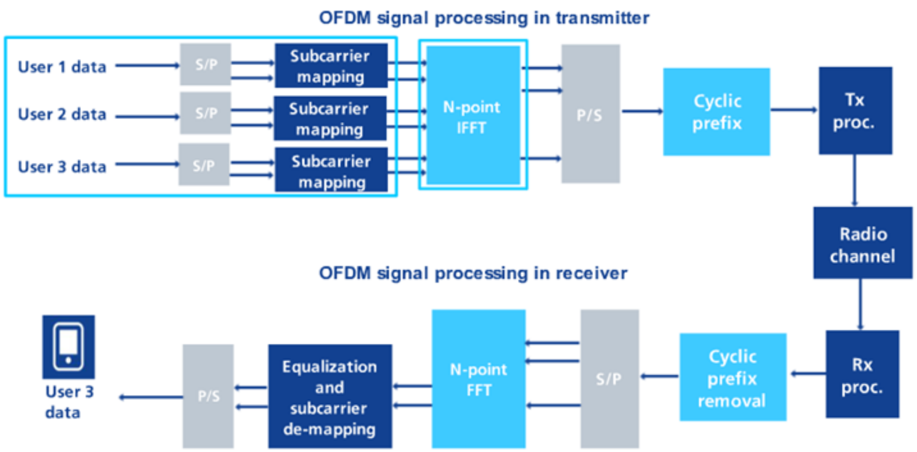
Introduction

- The Cellular Range Telemetry (CRTM) and Flightline Radio Network (FRN) projects explore the use of 3GPP Long Term Evolution – Advanced (LTE-A) for airborne and ground-based telemetry links
- **This presentation will look at**
  - **LTE RF carrier configurations**
  - **How spectrum is shared between multiple users within the LTE system**
  - **RF characteristics of LTE downlink and uplink signals**
- **In the context of these projects:**
  - **The AMT aircraft-mounted equipment operates as an LTE "User Equipment" (UE) device**
  - **Each AMT ground stations operates as an LTE "eNodeB" (base station)**
  - **LTE downlink = ground-to-air communication (eNodeB Tx / UE Rx)**
  - **LTE uplink = air-to-ground communication (UE Tx / eNodeB Rx)**

This presentation will focus on the LTE uplink, since the primary goal of these projects is delivery of telemetry data from the aircraft to the ground network

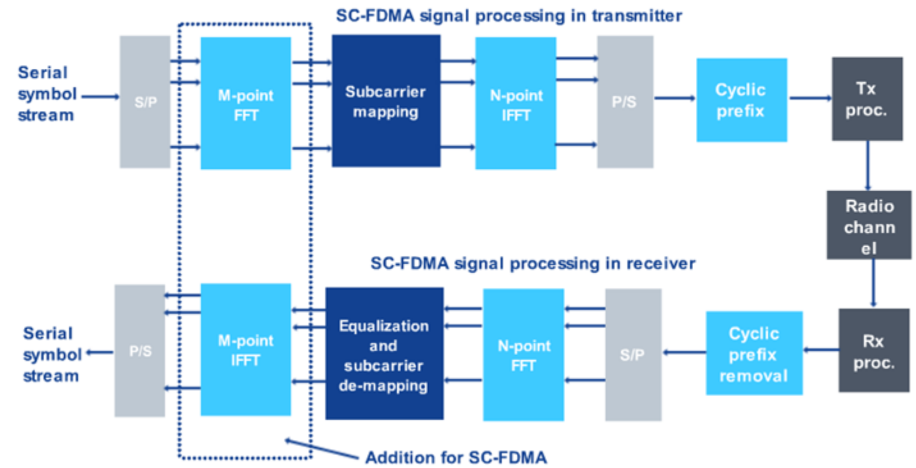
LTE carrier generation

OFDMA LTE downlink



From 3GPP Technical Standard (TS) 36.211 Section 6

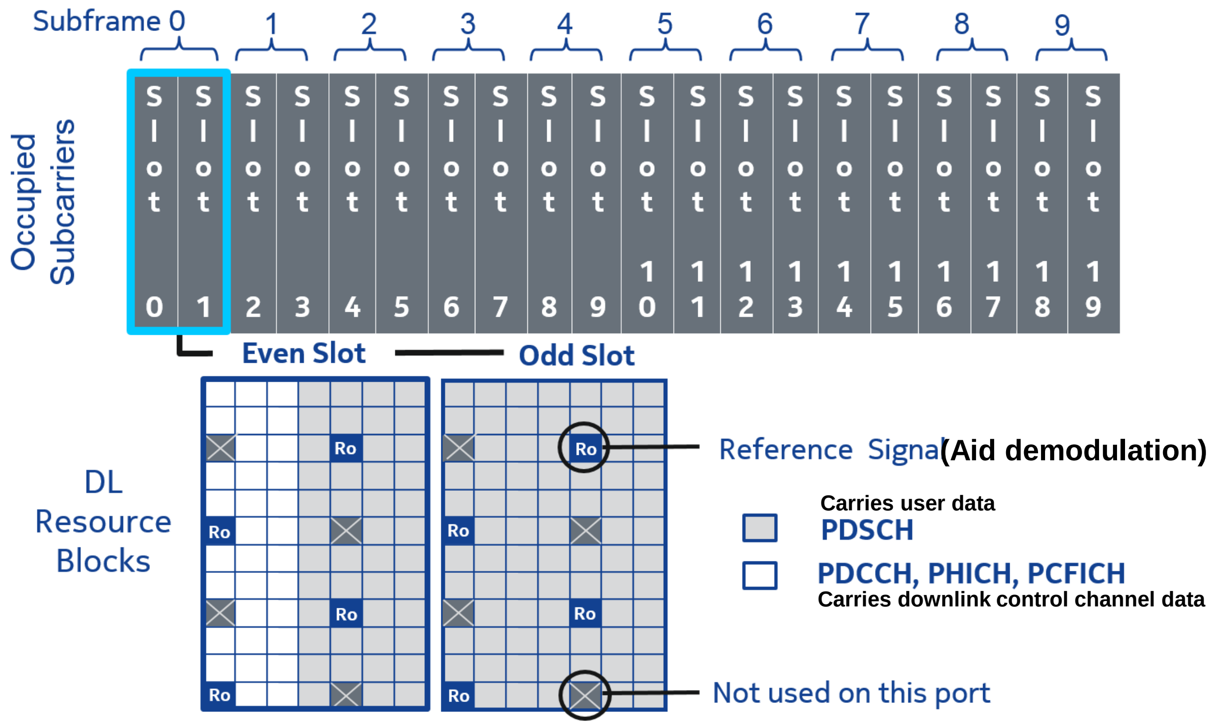
SC-FDMA LTE uplink



From 3GPP Technical Standard (TS) 36.211 Section 5

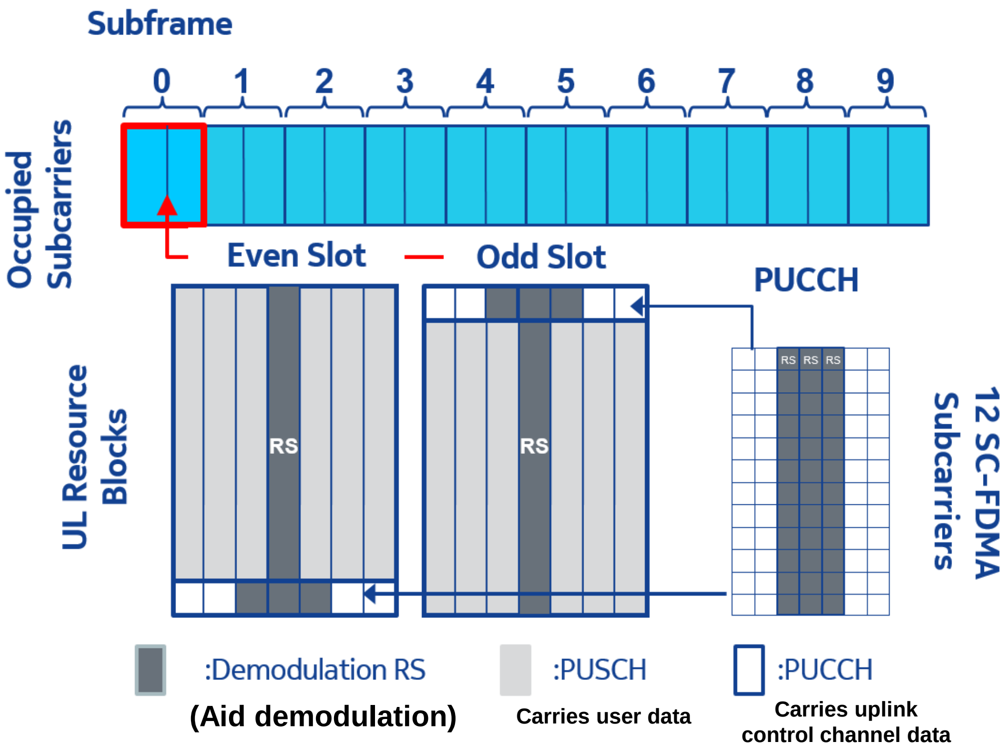
Downlink channels and resource mapping

- In the time domain:
  - 1 slot = 0.5msec
  - 1 subframe = 2 slots (1msec)
  - 10 sub-frames = one frame (10msec)
  - Synchronization signals are embedded twice per frame
  - Master Information Block (MIB) is transmitted once per frame
- In the frequency domain:
  - The OFDM process modulates data onto individual sub-carriers, which are 15kHz apart
  - 12 sub-carriers are grouped into a resource block, which occupies 180kHz in frequency
  - The number of resource blocks available for data transmission depends on the carrier bandwidth definition
- Scheduling user data
  - For each sub-frame, the scheduler determines which users will be allocated which resource blocks



Uplink channels and resource mapping

- In the time domain:
  - Same frame structure as downlink
  - No synchronization signals or Master Information Block required for the uplink
- In the frequency domain:
  - Same sub-carrier structure as downlink
  - The number of resource blocks available for data transmission depends on the carrier bandwidth definition and the number of resource blocks assigned for PUCCH
- Scheduling user data
  - For each sub-frame, the scheduler determines which users will be allocated which resource blocks and sends the appropriate uplink transmission grants to each UE scheduled for that interval.



Uplink user data capacity

- When a UE registers with the LTE system, it communicates its data buffer status to the eNodeB
- The uplink scheduler manages data transmission from UEs with data to send such that carrier capacity is used efficiently and UEs are served fairly
  - **For terrestrial systems, this process must be capable of handling several hundred UEs**
  - **For test range applications, maximum user density in any one geographical space is likely 4 or less**
- Amount of data scheduled per sub-frame determined by Modulation Coding Scheme (MCS) used for each UE
  - **MCS choice based on measured Signal to Interference + Noise (SINR) and UE power headroom**
  - **Each MCS value has an associated coding rate and modulation order, which determine what the payload for the scheduling interval will be.**

Example: Maximum throughput per carrier for a single UE

From Table 8.6.1-1 Modulation, TBS index and redundancy version table for PUSCH			*FDD UL Maximum Throughput (Mbps)*								
			10MHz bandwidth (50PRB)			*15MHz bandwidth (75PRB)*			*20MHz Bandwidth (100 PRB)*		
MCS Index I_{MCS}	*Modulation Order Q_m*	*TBS Index I_{TBS}*	*PUCCH Size = 4*	*PUCCH Size = 6*	*PUCCH Size = 8*	*PUCCH Size = 4*	*PUCCH Size = 6*	*PUCCH Size = 8*	*PUCCH Size = 4*	*PUCCH Size = 6*	*PUCCH Size = 8*
0		0	1.26	1.22	1.16	1.99	1.93	1.86	2.66	2.60	2.54
1		1	1.67	1.61	1.54	2.60	2.54	2.47	3.50	3.50	3.37
2		2	2.09	1.99	1.86	3.24	3.11	2.98	4.26	4.26	4.14
3		3	2.66	2.54	2.47	4.14	4.01	3.88	5.54	5.54	5.35
4		4	3.24	3.11	2.98	5.16	4.97	4.78	6.97	6.71	6.46
5	QPSK	5	4.01	3.88	3.75	6.20	5.99	5.99	8.50	8.25	7.99
6		6	4.78	4.58	4.39	7.48	7.22	6.97	9.91	9.91	9.53
7		7	5.74	5.35	5.16	8.76	8.50	8.25	11.83	11.45	11.45
8		8	6.46	6.20	5.99	9.91	9.53	9.53	13.54	12.96	12.96
9		9	7.22	6.97	6.71	11.06	11.06	10.68	15.26	14.69	14.69
10		10	7.99	7.74	7.48	12.58	12.22	11.83	16.99	16.42	16.42
11		10	7.99	7.74	7.48	12.58	12.22	11.83	16.99	16.42	16.42
12		11	9.14	8.76	8.50	14.11	14.11	13.54	19.08	19.08	18.34
13		12	10.68	9.91	9.53	16.42	15.84	15.26	22.15	21.38	21.38
14		13	11.83	11.45	10.68	18.34	17.57	16.99	24.50	24.50	23.69
15	16QAM	14	12.96	12.58	12.22	20.62	19.85	19.08	27.38	27.38	26.42
16		15	14.11	13.54	12.96	22.15	21.38	20.62	29.30	29.30	28.34
17		16	14.69	14.11	13.54	22.92	22.15	22.15	31.70	30.58	30.58
18		17	16.42	15.84	15.26	25.46	24.50	24.50	35.16	34.01	32.86
19		18	18.34	17.57	16.42	28.34	27.38	26.42	37.89	37.89	36.70
20		19	19.85	19.08	18.34	30.58	29.30	29.30	40.58	40.58	39.23
21		19	19.85	19.08	18.34	30.58	29.30	29.30	40.58	40.58	39.23
22		20	21.38	20.62	19.85	32.86	31.70	31.70	45.35	43.82	42.37
23		21	22.92	22.15	21.38	35.16	35.16	34.01	48.94	46.89	46.89
24	64QAM	22	24.50	23.69	22.92	37.89	36.70	36.70	51.02	51.02	48.94
25		23	26.42	25.46	24.50	40.58	39.23	37.89	55.06	55.06	52.75
26		24	28.34	26.42	25.46	43.82	42.37	40.58	59.26	57.34	57.34
27		25	29.30	28.34	26.42	45.35	43.82	42.37	61.66	59.26	59.26
28		26	34.01	32.86	30.58	52.75	51.02	48.94	71.11	68.81	68.81

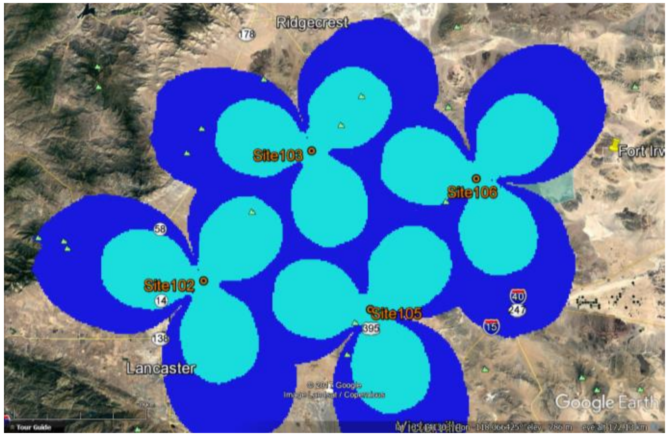
Increasing modulation order
+ **larger** coding rate =
Higher throughput

Uplink channel - summary

- The maximum uplink throughput for a UE is determined by channel configuration, channel conditions, path loss, and how many other users are sharing the same channel
- The maximum capacity of an uplink LTE carrier depends on the bandwidth, channel conditions and path loss of each UE scheduled in the same interval
- The process of a UE connecting to the system, indicating it has data to send, sending data, and moving across coverage areas is totally automated within the LTE system
- For flightline applications:
  - **Path loss is low and received SINR is high, so UEs will be scheduled with maximum MCS**
  - **Throughput per user and carrier capacity will be high**
  - **Density of aircraft on ground and data requirements for each aircraft will drive system design**
- For airborne test segments (CRTM) applications:
  - **Path loss and received SINR are variable, so UEs will be scheduled with varying MCS**
  - **Throughput per user and carrier capacity will be lower**
  - **Link budget considerations will drive system design**

Deployment of LTE carriers for RF coverage

- Cellular approach to RF coverage
  - **RF coverage is attained using three “sectors” of coverage around a single site**
  - **Each sector is driven by an antenna and Remote Radio Head (RRH). All RRHs at a site are connected to a single LTE baseband unit**
  - **Each sector contains 1 or more LTE carriers (“cells” in 3GPP speak). The number of carriers within a sector depends on the data throughput required within that sector**
- Spectrum usage
  - **Typically all sectors contain the same number of carriers, and each carrier can be thought of as part of a single-frequency layer that extends across the system. This allows the capacity of a single LTE carrier to be re-used many times across the system**



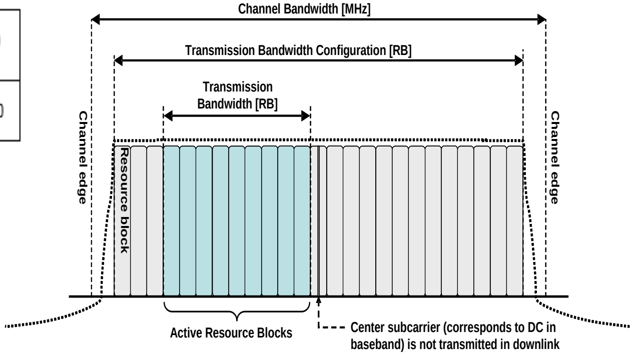
- Inter-cell interference due to single-frequency layers
  - **Downlink interference can be managed through frequency selective scheduling (low throughput requirements)**
  - **Uplink inter-cell interference is expected to be most prevalent in FRN systems and can be managed through use of**
    - **Coordinated Multi-point reception (CoMP)**
    - **Interference Rejection Combining (IRC)**
    - **Use of narrow beam antennas**

Table 5.6-1 Transmission bandwidth configuration N_{RB} in E-UTRA channel bandwidths

Channel bandwidth $BW_{Channel}$ [MHz]	1.4	3	5	10	15	20
Transmission bandwidth configuration N_{RB}	6	15	25	50	75	100

- **LTE carriers can be placed channel edge to channel edge without causing adjacent channel interference**
- **UE out-of-channel emissions at -25dBm/30kHz at 1MHz from channel edge**
- **UE out-of-channel emissions at -25dBm/30kHz at 10MHz from channel edge**

Figure 5.6-1 Definition of Channel Bandwidth and Transmission Bandwidth Configuration for one E-UTRA carrier



Effects of data load on LTE carriers

GBR = Guaranteed Bit Rate

Standard (non-GBR) bearer channel is default when User Equipment (UE) attaches to an LTE system

Request for higher QoS triggers set-up of a GBR bearer channel for that UE

20MHz LTE Uplink carrier Maximum throughput: 45Mbps (assuming 16QAM Max MCS

Using QoS not as important for FRN applications where RF conditions are good, but will be important for CRTM (airborne) applications where channel conditions change as the test article moves across the range

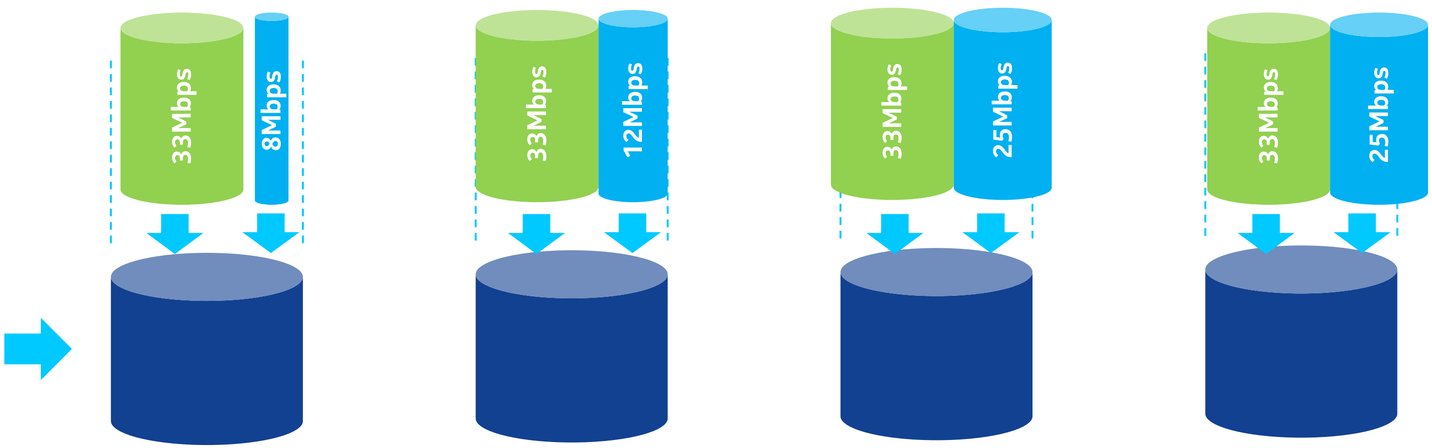
Using standard (non-GBR) bearer channels

Offered data is less than LTE carrier capacity

Offered data is at LTE carrier capacity

Offered data is more than LTE carrier capacity

Offered data is more than LTE carrier capacity, but critical data sent via GBR bearer channel



All data gets through with low latency and zero packet loss

Latency and packet loss begin to rise due to scheduling constraints

Packet loss may be OK for TCP applications

Not OK for UDP (AMT)

Throughput limited to carrier capacity. “Best effort” scheduling shares the available throughput between streams

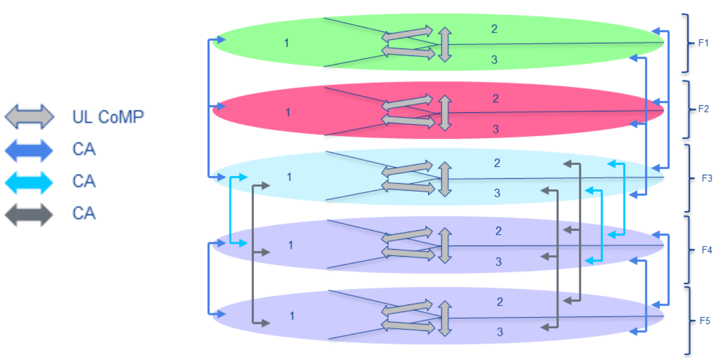
Not OK for most applications

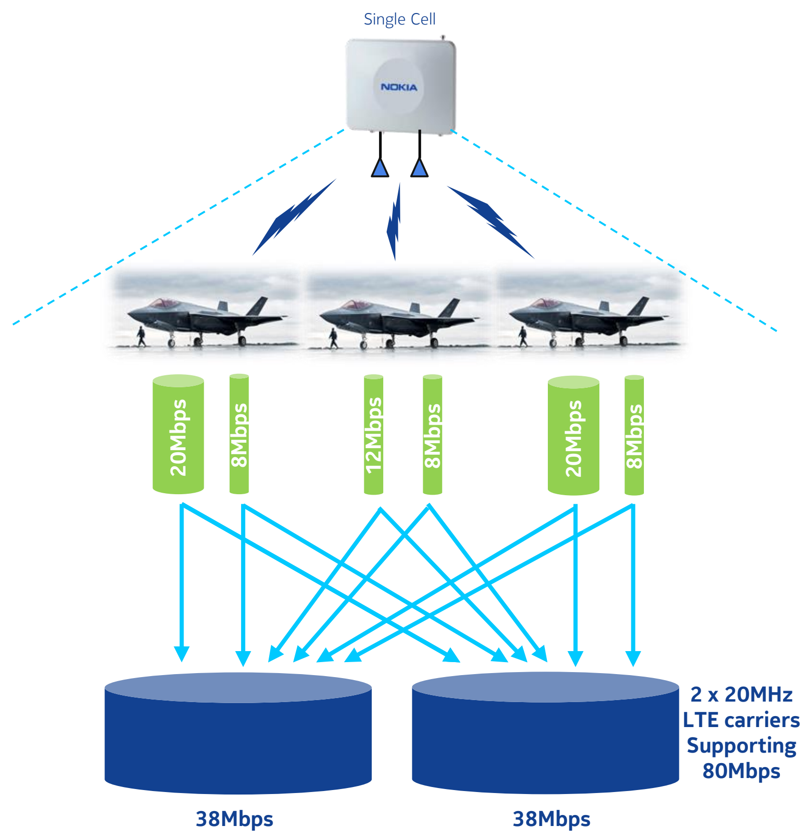
Data sent via GBR bearer gets through with no packet loss and low latency

Non-GBR stream packet loss and latency suffer

Using **carrier aggregation to increase capacity**

- To avoid the bottlenecks described on the previous slide, additional carriers can be deployed
  - Each additional carrier adds capacity in the coverage area
  - Individual carrier capacity may not be used efficiently when data is being sent over a few large streams
- Carrier Aggregation allows two or more carriers to be treated as a single spectrum resource
  - Allows any stream to be divided and sent over carriers in the aggregation group





Summary

- The process of a UE connecting to the system, indicating it has data to send, sending data, and moving across coverage areas is totally automated within the LTE system
- RF planning for flightline networks and airborne test range networks are driven by different requirements
- For flightline (FRN) applications:
  - **Carrier capacity will be high because of excellent signal quality conditions**
  - **Density of aircraft on ground will probably require multiple frequency layers with carrier aggregation**
  - **LTE features supporting uplink interference mitigation will be turned on**
- For airborne test segments (CRTM) applications:
  - **Density of airborne test articles will be lower than on the flightline, but throughput per carrier will be lower due to channel conditions**
  - **Lower per carrier capacity will result in deploying multiple frequency layers with carrier aggregation**