FT Scenario 1

Mission Suddenly Requires High Bandwidth For Safety of Flight Data

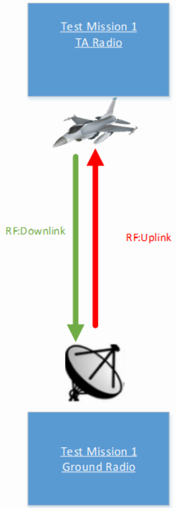
F-22 Coating Upgrades

Adapted from a flight test that occurred in 2005

Brief Description

A fighter has a mission with a fixed scheduled transmission bandwidth. During the flight test, flight crew encountered heavy vibration. As a result, the requirement for safety data increased to make sure everything is fine. Now the mission needs a higher amount of bandwidth to be able to send the safety data down to the ground station, in order to continue to fly. For this scenario, range bandwidth is available.

Voice and safety data need to be guaranteed for the test mission to be successful.



Test Article

Aircraft: F-22 Raptor

Range Infrastructure

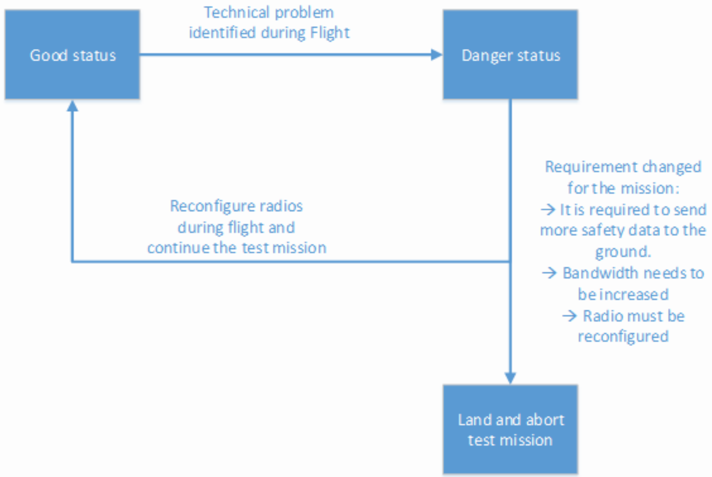
- Range Network:
  - Typically large military range e.g. Edwards Air Force Flight Test Center
- Equipment Used:
  - Ground Station Tracking Antenna and related network infrastructure
  - MCR Processing live data
- Equipment Available:
  - All in use

Static Scheduling

Before the start of the mission the radios are individually configured for the described test mission with the following QoS (Quality of Service):

- Voice: 50 Kb/s
- Safety: 100 Kb/s
- Voice and safety needs to be guaranteed during the entire mission
- Bulk: 1000 Kb/s

Flight Test Operation Flow



Associated Constraints

- Physical limit on amount of bandwidth that can be achieved
- Schedule must be valid
- Latency should be constrained under 50ms

Cost Metrics

Cost For Retrofit = Cost Per Flying Hour (CPFH) * X + Other Costs

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CPFH: Cost per Flying Hour (Well-known DoD cost metric) which includes Operating and Support costs such as Fuel, Consumables, and Maintenance costs

Other Costs: Instrumentation Cost ($0) + Test Planning (~$0) + Roll Out Cost + Scheduling Cost + Post Fly Analysis (~$0)

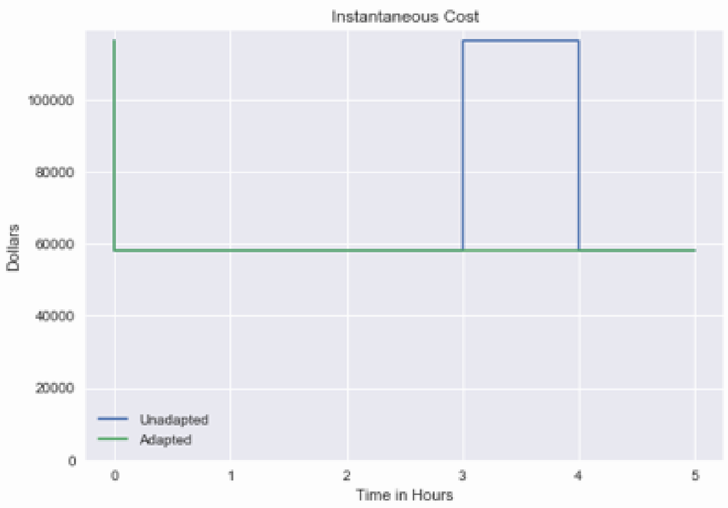
CPFH For the F-22 Raptor: **$58,059.00**

Assumptions: (1) Aircraft was already instrumented (2) We approximate the Rollout Costs and Scheduling Costs to be ~ the cost of an hour cost

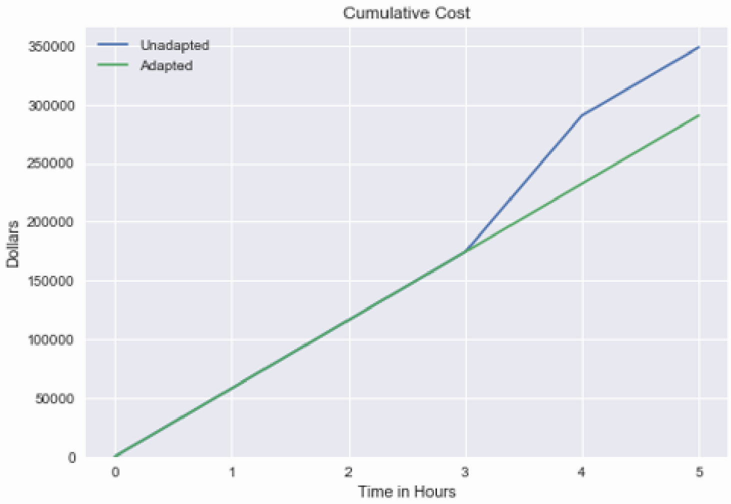
Cost Metric Instantaneous Cost

- Unadapted - FT mission encountered a problem after T=3 which required landing and repeating the test again

- Adapted - FT mission was accomplished successfully without having to land

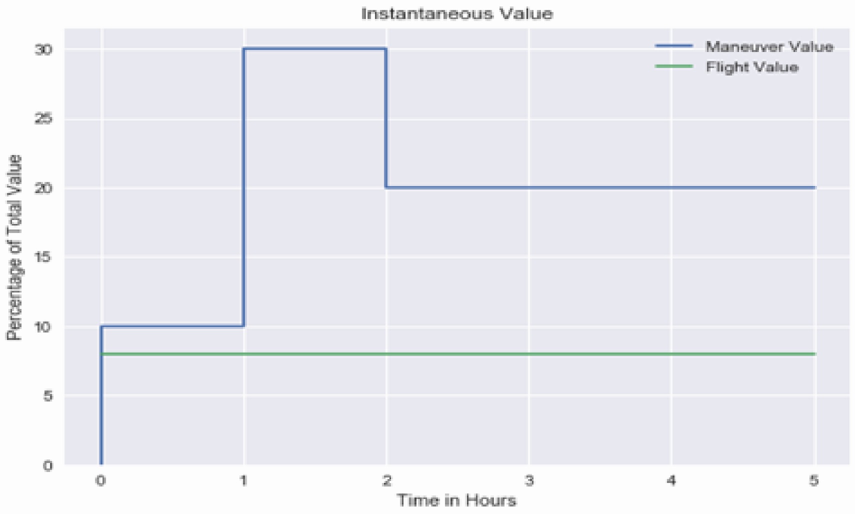


Cost Metric Cumulative Cost

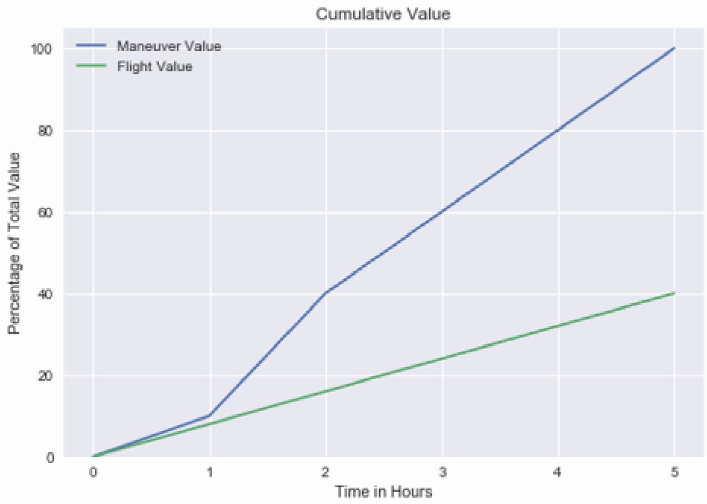


Program Value Function

- Maneuver value is the purpose of the flight test
- Flight value is some value gained by having the plane in the air



Program Value Function

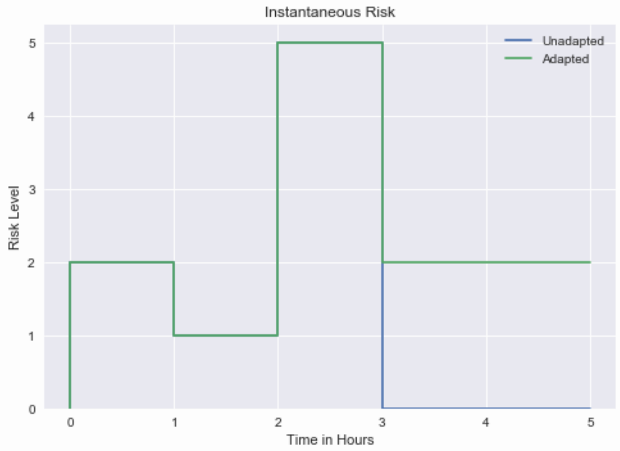


Risk Metric

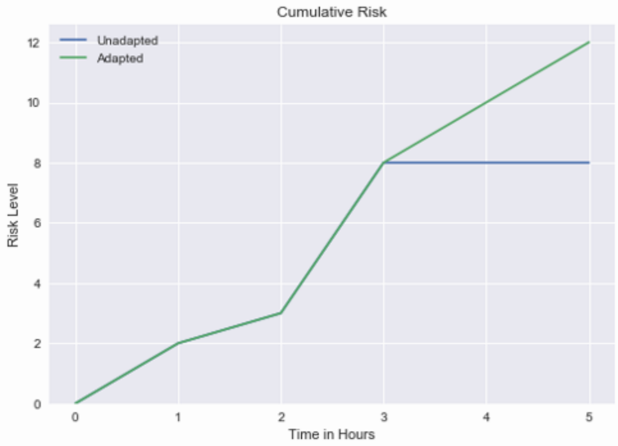
- Measures the future uncertainties in achieving the test mission within the defined cost and schedule constraints

Risk Probability that a particular event will occur		
Level	**Value**	**Criteria**
5	Near certainty	Everything points to this becoming a problem
4	Very likely	High chance of this becoming a problem
3	Likely (50/50)	There is an even chance this may turn into a problem once in a while
2	Unlikely	Risk like this may turn into a problem once in a while
1	Improbable	Not much chance this will become a problem

Risk Metric



Instantaneous Risk
Unadapted
Adapted
Risk Level
Time in Hours
0
1
2
3
4
5



Cumulative Risk
Unadapted
Adapted
Risk Level
Time in Hours
0
2
4
6
8
10
12

Requirement Changes after Event Happens

	Requirements Before Event	Requirements After Event
Voice	50 Kb/s	50 Kb/s
Safety	100 Kb/s	150 Kb/s
Bulk	1000 Kb/s	1000 Kb/s

QoS Policies

- Where is QoS Policy defined in MDL?

  `<TestMission>\<QoSPolicy>\<ServiceLevelProfiles>`

- The Mission Service Level Profiles (MSLP) are defined for each link to handle Quality of Service (QoS) IP routing across the RF links that are defined for radio to radio wireless RF communication

- Each MSLP defines a specific set of rules for IP routing that are applied to the RadioLink that is referenced

Priority Levels

IEEE 802.1Q PCP – IEEE P802.1p	DSCP Category Description	Expected Use Within TmNS-based System
0 – Best Effort	Best Effort	DSCP 0: General Network Traffic (e.g. FTP)
1 – Background	Class 1	DSCP 8: RC Delivery at Normal Priority & System Management Status
2 – Excellent Effort	Class 2	DSCP 16: LTC Delivery
3 – Critical Applications	Class 3	DSCP 24: RC Delivery at High Priority
4 – "Video," < 100 ms latency & jitter	Class 4	DSCP 32: System Management Control & Video
5 – "Voice," < 10 ms latency and jitter	Expedited Forwarding (EF)	DSCP 40: Voice
6 – Internetwork Control	Control (used for IP routing protocols)	DSCP 48: RF Network Messages
7 – Network Control	Control (link layer and routing protocol keep alive)	DSCP 56: RF Network Messages

QoS Policy in MDL

Where do we set the QoS Policies for the uplink and downlink radio link?

```xml
<QoSPolicies>
  <QoSPolicy ID="GR1_to_TA1_MissionSLP">
      <Name>GR1_to_TA1_MissionSLP</Name>
      <Description>GR1_to_TA1 Mission Service Level Profile for Test Mission 1
      </Description>
      <QoSPolicyID>0x01123600</QoSPolicyID>
      <RadioLinkRefs>
          <RadioLinkRef IDREF="GndRadio_to_TA"/>
      </RadioLinkRefs>
      <Priority>4</Priority>
      <LinkManagementMinCapacity>
          <Value>100000</Value>
          <BaseUnit>BitPerSecond</BaseUnit>
      </LinkManagementMinCapacity>
      <AssuredCapacity>
          <Value>200000</Value>
          <BaseUnit>BitPerSecond</BaseUnit>
      </AssuredCapacity>
      <ServiceLevelProfiles>
          <ServiceLevelProfile ID="GR1_to_TA1_SLP_1_0">
      </ServiceLevelProfiles>
  </QoSPolicy>
```

Voice Requirement in MDL


```xml
<ServiceLevelProfile ID="GR1_to_TA1_SLP_1_20">
    <Name>GR1_to_TA1_SLP_1_20</Name>
    <Description>HTB class for Expedited Forwarding Voice Traffic</Description>
    <SLPHandle>0x00010014</SLPHandle>
    <QueueConstruct>
        <Class>
            <HTB>
                <Priority>2</Priority>
                <Rate>
                    <Value>50000</Value>
                    <BaseUnit>BitPerSecond</BaseUnit>
                </Rate>
                <Ceiling>
                    <Value>100000</Value>
                    <BaseUnit>BitPerSecond</BaseUnit>
                </Ceiling>
            </HTB>
        </Class>
    </QueueConstruct>
    <TrafficFilters>
        <TrafficFilter>
            <Name>TBD name 2</Name>
            <Description>Filter for Voice traffic DCSP range 40-47 (class 5)</Description>
            <ParentQDiscHandle>0x00010000</ParentQDiscHandle>
            <Protocol>IPv4</Protocol>
            <Priority>3</Priority>
            <Classifier>PacketFields</Classifier>
            <Conditions>
                <Condition>
                    <MatchField>
                        <Protocol>IPv4</Protocol>
                        <Offset>1</Offset>
                        <FieldWidth>8-bit</FieldWidth>
                        <Pattern>0xa0</Pattern>
                        <Mask>0xe0</Mask>
```

Safety Requirement in MDL (Before)


```xml
<ServiceLevelProfile ID="TA1_to_GndGrp1_SLP_1_301">
    <Name>TA1_to_GndGrp1_SLP_1_301</Name>
    <Description>htb DSCP Class Selector 3 (including all Class 3) traffic</Description>
    <SLPHandle>0x0001012d</SLPHandle>
    <QueueConstruct>
        <Class>
            <HTB>
                <Priority>2</Priority>
                <Rate>
                    <Value>100000</Value>
                    <BaseUnit>BitPerSecond</BaseUnit>
                </Rate>
                <Ceiling>
                    <Value>200000</Value>
                    <BaseUnit>BitPerSecond</BaseUnit>
                </Ceiling>
            </HTB>
        </Class>
    </QueueConstruct>
    <TrafficFilters>
        <TrafficFilter>
            <Name>TBD name 4</Name>
            <Description>Filter for RC Delivery at High Priority DCSP range 24-31 (class 3)</Description>
            <ParentQDiscHandle>0x00010000</ParentQDiscHandle>
            <Protocol>IPv4</Protocol>
            <Priority>5</Priority>
            <Classifier>PacketFields</Classifier>
            <Conditions>
                <Condition>
                    <MatchField>
                        <Protocol>IPv4</Protocol>
                        <Offset>1</Offset>
                        <FieldWidth>8-bit</FieldWidth>
                        <Pattern>0x60</Pattern>
                        <Mask>0xe0</Mask>
                    </MatchField>
                </Condition>
            </Conditions>
        </TrafficFilter>
    </TrafficFilters>
```

Safety Requirement in MDL (After)


```xml
<ServiceLevelProfile ID="TA1_to_GndGrp1_SLP_1_301">
    <Name>TA1_to_GndGrp1_SLP_1_301</Name>
    <Description>htb DSCP Class Selector 3 (including all Class 3) traffic</Description>
    <SLPHandle>0x0001012d</SLPHandle>
    <QueueConstruct>
        <Class>
            <HTB>
                <Priority>2</Priority>
                <Rate>
                    <Value>150000</Value>
                    <BaseUnit>BitPerSecond</BaseUnit>
                </Rate>
                <Ceiling>
                    <Value>250000</Value>
                    <BaseUnit>BitPerSecond</BaseUnit>
                </Ceiling>
            </HTB>
        </Class>
    </QueueConstruct>
    <TrafficFilters>
        <TrafficFilter>
            <Name>TBD name 4</Name>
            <Description>Filter for RC Delivery at High Priority DCSP range 24-31 (class 3)</Description>
            <ParentQDiscHandle>0x00010000</ParentQDiscHandle>
            <Protocol>IPv4</Protocol>
            <Priority>5</Priority>
            <Classifier>PacketFields</Classifier>
            <Conditions>
                <Condition>
                    <MatchField>
                        <Protocol>IPv4</Protocol>
                        <Offset>1</Offset>
                        <FieldWidth>8-bit</FieldWidth>
                        <Pattern>0x60</Pattern>
                        <Mask>0xe0</Mask>
                    </MatchField>
                </Condition>
            </Conditions>
        </TrafficFilter>
    </TrafficFilters>
    <ServiceLevelProfiles>
```

Classic Solution

- Land and abort test
  - Increases cost of testing because we will have to start the test over
    - Impact flight test schedule

- No MDL changes needed for this solution

Suggested Solution

- MDL Reconfiguration
  - RadioLink element is where most of the changes need to be done for both Radio (TA and Ground)
    - Describes a one-way connection two radio point
    - TransmissionSchedule element which describes the scheduling parameters for a static schedule
    - In this case we need to schedule TxOp assignment for the TA Radio and the Ground Radio as appropriate for the scenario requirement change

TA Radio MDL Configuration (Before)


```xml
<RadioLink ID="TA_to_GndRadio">
    <Name>TA_to_GndRadio</Name>
    <Description>TA_to_GndRadio Downlink for Test Mission 1</Description>
    <SourceRadioRef IDREF="TA_RadioTMA1"/>
    <DestinationRadioGroupRef IDREF="GROUND_GROUP_1"/>
    <TxRxEnable>true</TxRxEnable>
    <HeartbeatTimeout>65535</HeartbeatTimeout>
    <EncryptionEnabled>false</EncryptionEnabled>
    <EncryptionKeyID>0</EncryptionKeyID>
    <TransmissionSchedule>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>12500</StartUSec>
            <StopUSec>24000</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>37500</StartUSec>
            <StopUSec>49000</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>62500</StartUSec>
            <StopUSec>74000</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>87500</StartUSec>
            <StopUSec>99000</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
    </TransmissionSchedule>
</RadioLink>
```

Ground Radio MDL Configuration (Before)

```xml
<RadioLink ID="GndRadio_to_TA">
    <Name>GndRadio_to_TA</Name>
    <Description>GndRadio_to_TA Uplink for Test Mission 1</Description>
    <SourceRadioRef IDREF="GR1"/>
    <DestinationRadioGroupRef IDREF="GROUND_GROUP_1"/>
    <TxRxEnable>true</TxRxEnable>
    <HeartbeatTimeout>65535</HeartbeatTimeout>
    <EncryptionEnabled>false</EncryptionEnabled>
    <EncryptionKeyID>0</EncryptionKeyID>
    <TransmissionSchedule>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>0</StartUSec>
            <StopUSec>11500</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>25000</StartUSec>
            <StopUSec>36500</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>50000</StartUSec>
            <StopUSec>61500</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>75000</StartUSec>
            <StopUSec>86500</StopUSec>
            <TxOpTimeout>0</TxOpTimeout>
        </TxOp>
    </TransmissionSchedule>
```

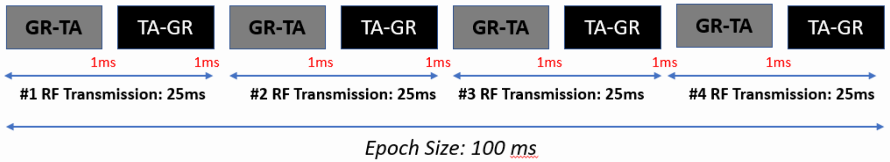
TA Radio MDL Configuration (After)


```xml
<RadioLinks>
  <RadioLink ID="TA_to_GndRadio">
      <Name>TA_to_GndRadio</Name>
      <Description>TA_to_GndRadio Downlink for Test Mission 1</Description>
      <SourceRadioRef IDREF="GR1"/>
      <DestinationRadioGroupRef IDREF="GROUND_GROUP_1"/>
      <TxRxEnable>true</TxRxEnable>
      <HeartbeatTimeout>65535</HeartbeatTimeout>
      <EncryptionEnabled>false</EncryptionEnabled>
      <EncryptionKeyID>0</EncryptionKeyID>
      <TransmissionSchedule>
          <TxOp>
              <CenterFrequencyHz>4919500000</CenterFrequencyHz>
              <StartUSec>12500</StartUSec>
              <StopUSec>24000</StopUSec>
              <TxOpTimeout>255</TxOpTimeout>
          </TxOp>
          <TxOp>
              <CenterFrequencyHz>4919500000</CenterFrequencyHz>
              <StartUSec>49000</StartUSec>
              <StopUSec>74000</StopUSec>
              <TxOpTimeout>255</TxOpTimeout>
          </TxOp>
          <TxOp>
              <CenterFrequencyHz>4919500000</CenterFrequencyHz>
              <StartUSec>87500</StartUSec>
              <StopUSec>99000</StopUSec>
              <TxOpTimeout>255</TxOpTimeout>
          </TxOp>
      </TransmissionSchedule>
  </RadioLink>
```

Ground Radio MDL Configuration (After)


```xml
<RadioLink ID="GndRadio_to_TA">
    <Name>GndRadio_to_TA</Name>
    <Description>GndRadio_to_TA Uplink for Test Mission 1</Description>
    <SourceRadioRef IDREF="GR1"/>
    <DestinationRadioGroupRef IDREF="GROUND_GROUP_1"/>
    <TxRxEnable>true</TxRxEnable>
    <HeartbeatTimeout>65535</HeartbeatTimeout>
    <EncryptionEnabled>false</EncryptionEnabled>
    <EncryptionKeyID>0</EncryptionKeyID>
    <TransmissionSchedule>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>0</StartUSec>
            <StopUSec>11500</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>25000</StartUSec>
            <StopUSec>48000</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
        <TxOp>
            <CenterFrequencyHz>4919500000</CenterFrequencyHz>
            <StartUSec>75000</StartUSec>
            <StopUSec>86500</StopUSec>
            <TxOpTimeout>255</TxOpTimeout>
        </TxOp>
    </TransmissionSchedule>
</RadioLink>
```

Transmission Schedule Before Adaptation



GR-TA: 0 ms – 11.5 ms
TA-TA: 12.5 ms – 24 ms
TA-TA: 25 ms – 36.5 ms
TA-GR: 37.5 ms – 49 ms
GR-TA: 50 ms – 61.5 ms
TA-TA: 62.5 ms – 74 ms
TA-TA: 75 ms – 86.5 ms
TA-GR: 87.5 ms – 99 ms

- Requirement: 50ms latency (actual is 25 ms)
- Epoch size: 100 ms

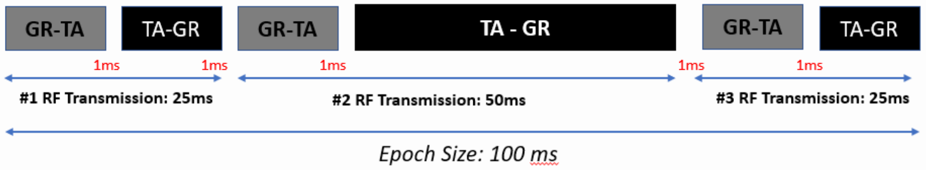
  <RANConfiguration>,<EpochSize>100</EpochSize>

We suggest, to have 4 transmission per link then I need 100/25=4
We configured our Guard Band to be 1 ms

<RANConfiguration ID="RANConfig1">

<MaxGuardTimeSec>0.001</MaxGuardTimeSec>

Transmission Schedule After Adaptation



We are still meeting the latency of 50ms requirements.

GR-TA: 0 ms – 11.5 ms
TA-TA: 12.5 ms – 24 ms
TA-TA: 25 ms – 48 ms
TA-GR: 49 ms – 74 ms
TA-TA: 75 ms – 86.5 ms
TA-GR: 87.5 ms – 99 ms

Rules

- We presented one sample transmission schedule
- Others can also be an option as long as it meets the latency requirement

Sources

- https://www.pmi.org/learning/library/project-management-cost-estimate-costs-5256
- http://www.businessinsider.com/air-force-plane-cost-per-flight-hour-chart-2016-3
  - F22 and F35
- http://nation.time.com/2013/04/02/costly-flight-hours/
- https://www.rand.org/content/dam/rand/pubs/research_reports/RR1100/RR1178/RAND_RI