IETF 115 TVR BOF
Use Cases

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Overview

- Approach
- Format
- Use Cases
  - Local Resource Preservation
  - Adapting to External Conditions
  - Mobile Devices - with Predictable Connectivity

Approach and Format

- Constrain use cases to the problem statement
- Highlight *categories of problems*
  - What are the likely uses of this TVR information?
  - Seemed to bin into 3 “categories”.
  - Avoid re-stating the same “case” with irrelevant differences.
- Use Case:
  - The set of circumstances where a solution for one is a solution for all.
- Use Cases Format
  - **Assumptions**: Information thought necessary to get deterministic benefits.
  - **Possible TVR Benefits**: Anticipated benefits (OR not AND conditions).
  - **Exemplar**: Small illustrative example of the idea. One of likely many.

Use Case 1: Local Resource Preservation

Overview

https://commons.wikimedia.org/wiki/File:CSIRO_ScienceImage_3876_A_remote_sensing_node_part_of_CSIROs_Fleck_wireless_sensor_network_technology.jpg

- Nodes operate with limited resources (environment or design)
  - Limited power, thermal, storage.
  - Part of a node’s function is managing its own (local) resources.

- Local resource management dictates node function
  - Pause non-critical functions to extend node life
  - Pause functions to “conserve” resources for a future event (data collection)
  - Pause functions to allow return to a thermally safe environment
  - Activate functions to reclaim storage (data fusion, deletion, transmission)

- Possible TVR Benefits
  - Knowing when links will come (and go) can help nodes make local resource-preservation decisions.
  - Ex: Don’t plan on powering radios if there is no expectation of a link

Use Case 1: Local Resource Preservation

Assumptions and Possible TVR Benefits

The better we know these…

Assumptions

- **Resource expenditures are knowable.**
  - The amount of resources consumed for node functions can be planned in advance.
  - For example, the amount of battery power needed to transmit a data volume.
- **Resource accumulation is predictable.**
  - Nodes can predict when resources will recover over times.
    - Or there exists schedules for this information.
  - For example, how battery power will increase as a function of charge rates.
- **Resource management is consistent.**
  - The resource management functions of a node apply consistent cost functions to determine node behavior.
  - If node resource management changes too rapidly, decisions made at one point in time might be reversed as a later point in time.

The more likely we will achieve these…

Possible TVR Benefits

- **Power Savings.**
  - Radios may be turned off to allow other processing.
  - Generally, this may extend the battery life or allow node to perform some other power-intensive task.
- **Thermal Savings.**
  - Adapting processing around link availability may reduce thermal load.
- **Storage Savings.**
  - Storage reclamation can be planned as a function of future link availability (for transmission) or be used to determine when/how to delete data.
- **Data Delivery**
  - Managed resources on the node increase node's existence and participation in the network.

Use Case 1: Local Resource Preservation

Exemplar: A power-constrained wireless sensor network

- **Scheduled Node Transmissions**
  - Radios powered as a function of time.
  - Different nodes on at different times.
- **Assumptions**
  - Power expenditures known.
  - Power accumulation (solar) predictable.
  - Resource (radio) management same.
- **Dynamic Topology**
  - Connectivity changes over time.
  - There might never be a single end-to-end path.
  - Link up/down:
    - Predictable/Schedulable.
    - Communicable.

Assume a minimum local power to turn on radio.

```
           Node 1                      Node 2                      Node 3
P |                         P |   -------                 P |           --
o |   ----        --        o |  /        \               o |          /  \
w |~/~~~~\~~~~~/~~\~~       w |~/~~~~~~~~~\~~~~~~         w |~~~~~~~~/~~~~\~~~~
e |/      \    /    \       e |/            \             e |        /      \
r |        ---        -     r |              -----        r |-------          ---
  +---++----++----++-         +---++----++----++-           +---++----++----++-
      t1    t2    t3              t1    t2    t3                t1    t2    t3
            Time                        Time                          Time
```

Figure 1: Node Power Over Time

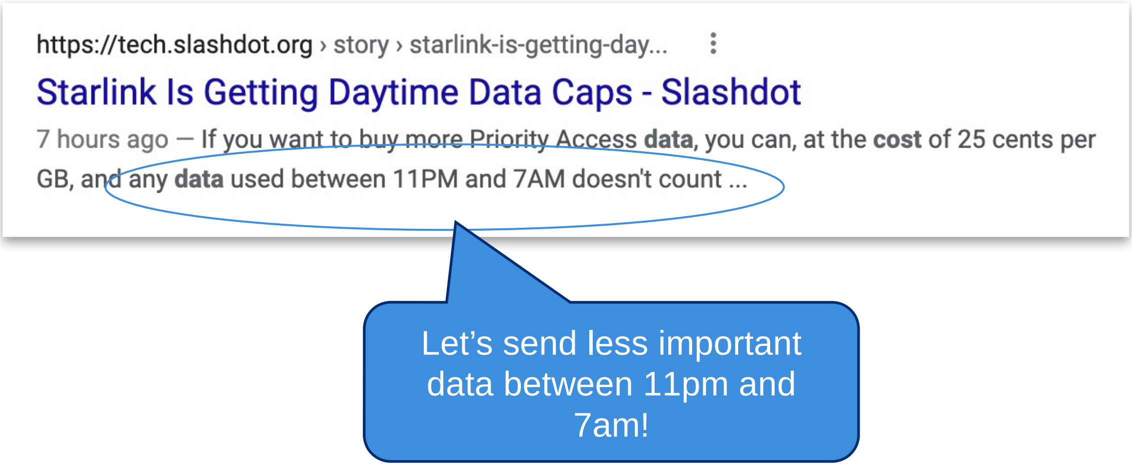
```
     +----------+         +----------+         +----------+
t1   |  Node 1  |---------|  Node 2  |         |  Node 3  |
     +----------+         +----------+         +----------+

     +----------+         +----------+         +----------+
t2   |  Node 1  |         |  Node 2  |---------|  Node 3  |
     +----------+         +----------+         +----------+

     +----------+         +----------+         +----------+
t3   |  Node 1  |         |  Node 2  |         |  Node 3  |
     +----------+         +----------+         +----------+
```

Figure 2: Topology over Time

Use Case 2: Adapting to External Conditions

Overview

- External costs associated with external conditions (e.g. use of local infrastructure).
  - Nodes that use existing wireless communications (such as a cellular infrastructure) must pay to communicate to and through that infrastructure.
  - Nodes supplied with electricity from an energy provider pay for the power they use.



- Not all costs are strictly financial
  - Environmental impacts, Green computing
- Possible TVR Benefits
  - The "cost" of transmissions may vary over time.
    - Adjacencies might be added or removed when their cost crosses thresholds.
  - Nodes can benefit from predicting/scheduling when data transmissions might optimize costs, environmental impacts, or other metrics associated with operation.

Use Case 2: Adapting to External Conditions

Assumptions and Possible TVR Benefits

Assumptions

- **Measureability.**
  - External conditions can be associated with node functions.
- **Predictability/Schedulability**
  - External conditions known in advance.
    - More than just "the current condition at the moment".
- **Persistence.**
  - External condition changes are infrequent enough that behavior can be adjusted in response to their changing.
- **Magnitude.**
  - Savings justify the efforts required to achieve them.

Possible TVR Benefits

- **Link Filtering.**
  - Links filtered based on cost - minimize use of high-cost links unless needed by type of traffic (e.g. high priority).
- **Burst Planning.**
  - If fewer transmissions save costs, nodes might accumulate data volume before transmission.
- **Environmental Measurement.**
  - Environmental conditions may greatly affect throughput vs goodput (such as clouds on an optical link or long distance RF transmission in a storm). Costs can be used to address this.
- **Data Delivery**
  - Data delivery less impacted by external conditions.

Use Case 2: Adapting to External Conditions

Exemplar: On/Off Peak Cellular Usage

Costs are “high” during On-Peak.

- **“Costs” vary by node**
  - Spatially distributed sensors.
  - Connecting through cellular access.
- **Assumptions**
  - Cost is measurable as data is charged by On/Off Peak data usage.
  - Cost is scheduled and changes relatively slowly (twice a day).
  - Cost magnitude may be significant given high overage fees.
- **Cost-Dynamic Topology**
  - Physical topology unchanged
  - Paths have different costs at different times.
  - Can calculate when is best time to use a given end-to-end path (t1 or t3).
  - Can calculate lowest cost path (store/forward) as combination t1 + t3.

```
      Node 1                          Node 2                    Node 3

C |          +---------      C |--+                      C |--------------+
o |          |               o |  |                      o |              |
s |          |               s |  |                      s |              |
t |-------+                  t |  +----------------      t |              +-------
  |                            |                           |
  +---++----++----++--         +----++----++----++--       +----++----++----++--
      t1    t2    t3                t1    t2    t3              t1    t2    t3
            Time                          Time                        Time
```

Figure 3: Data Cost Over Time

```
     +-----------+          +-----------+          +-----------+
t1   |  Node N1  |---LOW----|  Node N2  |---HIGH---|  Node N3  |
     +-----------+          +-----------+          +-----------+

     +-----------+          +-----------+          +-----------+
t2   |  Node N1  |---HIGH---|  Node N2  |---HIGH---|  Node N3  |
     +-----------+          +-----------+          +-----------+

     +-----------+          +-----------+          +-----------+
t3   |  Node N1  |---HIGH---|  Node N2  |----LOW---|  Node N3  |
     +-----------+          +-----------+          +-----------+
```

Figure 4: Data Exchange Cost over Time

```
     +-----------+          +-----------+
t1   |  Node N1  |---LOW----|  Node N2  |
     +-----------+          +-----------+
                            +-----------+          +-----------+
t3                          |  Node N2  |----LOW---|  Node N3  |
                            +-----------+          +-----------+
```

Figure 5: Data Cost using Storage

Use Case 3: Mobile Devices – with Predictable Connectivity

Overview

- Mobility can cause the loss of an adjacent link, due to:
  - Distance-related attenuation causes a mobile node to lose connectivity with one or more other nodes in the network.
    - **I drove far enough into a field that I lost cellular coverage**
  - External characteristics may cause the loss of links through occultation or other hazards of traversing a shared environment.
    - **I drove into a tunnel**
  - Nodes that can change the orientation of their communication terminals will also establish and lose connectivity with other nodes as a function of that motion.
    - **I pointed my antenna somewhere else.**
- Possible TVR Benefits
  - Expected loss of links are not seen as error conditions
    - Loss/resumption of a link is technically a change to topology
    - But expected loss/resumption of a link is not a radical change to a topology.
  - Expected resumption of a link does not always need to be rediscovered.
  - Predictability/Schedulability != reactivity.

https://commons.wikimedia.org/wiki/File:Google_Loon_-_Launch_Event.jpg

Use Case 3: Mobile Devices – with Predictable Connectivity

Assumptions and Possible TVR Benefits

Assumptions

- **Path Predictability/Schedulability.**
  - The path of a mobile node through its environment is known (or can be predicted) as a function of (at least) time.
    - No random motion
- **Environmental Knowledge.**
  - When otherwise well-connected mobile nodes pass through certain elements of their environment (such as a storm, a tunnel, or the horizon) they may lose connectivity. The duration of this connectivity loss is assumed to be predictable as a function of node mobility and the environment itself.

Possible TVR Benefits

- **Adjacent Link Expiration.**
  - Planned expiration does not need to incur error recovery (or always drop data).
- **Adjacent Link Resumption.**
  - Possible to predict/schedule when adjacency resumes.
    - May include recovery to a different link,.
- **Data Rate Adjustments.**
  - Knowledge of both mobility and environmental state may allow for prediction of data rates which may impact path computation.
- **Adjacent Link Filtering.**
  - A route computation might avoid an adjacency if that adjacency is likely to expire or degrade in the near future.

Use Case 3: Mobile Devices – with Predictable Connectivity

Exemplar: Networked LEO Constellation

- **LEO spacecraft links are short lived**
  - Passes of several minutes each.
  - Pass planning happens at ground terminals.
  - Need to understand what node is over what terminal when.
- **Assumptions**
  - Paths are predictable: motion and pointing can be understood in advance.
  - Environmental knowledge is predictable: The environment being transmitted to and through can be well understood.
- **Dynamic Topology**
  - Physical topology changes rapidly.
    - Internal network not so much (inter-satellite links)
    - Exit points (ground stations) very much.
  - Satellite handoffs need to be planned (even in close advance).

```
         .--.                    .--.                    .--.
  ####-| N1 |-####  <--->  ####-| N2 |-####  <--->  ####-| N3 |-####
         \__/                    \__/                    \__/
```

Figure 6: Three Sequential Spacecraft

```
         Spacecraft N1              Spacecraft N2              Spacecraft N3
 G |                        G |                        G |
 r |              +--+      r |         +--+           r |   +--+
 o |              |  |      o |         |  |           o |   |  |
 u |              |  |      u |         |  |           u |   |  |
 n |--------------+  +-     n |---------+  +-------    n |---+  +------------
 d |                        d |                        d |
   +----++----++----++--      +----++----++----++--      +----++----++----++--
       t1     t2     t3           t1     t2     t3           t1     t2     t3
             Time                       Time                       Time
```

Figure 7: Spacecraft Ground Contacts Over Time

```
      +-------+          +-------+
t1    |  N2   |----------|  N3   |
      +-------+          +---+---+
                             |
                            /|\
                           \___/
                            / \
                          Ground
                          Station
--------------------------------------------------------------------
      +-------+          +-------+          +-------+
t2    |  N1   |----------|  N2   |----------|  N3   |
      +-------+          +---+---+          +-------+
                             |
                            /|\
                           \___/
                            / \
                          Ground
                          Station
--------------------------------------------------------------------
                         +-------+          +-------+          +-------+
t3                       |  N1   |----------|  N2   |----------|  N3   |
                         +---+---+          +-------+          +-------+
                             |
                            /|\
                           \___/
                            / \
                          Ground
                          Station
--------------------------------------------------------------------
```

Figure 8: Constellation Topology Over Time