Link aggregation/bonding and load balancing with SAF products
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1. About LAG in Ethernet terminology

Link aggregation, load balancing, and link bonding are computer networking umbrella terms. They describe various methods of aggregating multiple network connections in parallel links to increase throughput beyond what a single connection could sustain, as well as provide redundancy in case one of the links fails.

From the network point of view, the link bonding is a single physical channel. Link bonding is Layer 1 aggregation of frames, which is delivered as a single physical link to Layer 2, whereas Ethernet aggregation (mostly Layer 2) and load balancing (Layer 3) are methods for combining two or more Ethernet paths.

**Link bonding** – Layer 1 aggregation based on frame or bit aggregation.

**Link aggregation** – Layer 2 aggregation is based on IEEE 802.3ad with MAC address hashing. Some implementations also allow Layer 3 aggregation based on hashing of IP address/ports.

**Load balancing** – Traffic segmentation based on pre-defined traffic path configuration, usually implemented in routers or Layer 3 switches. Traffic segmentation can be defined by VLANs, IP addresses, ports, etc., depending on options in the device. Load balancing can be applied on Layer 2 switches based on pre-defined paths per VLAN.

CFIP Lumina, PhoeniX and Marathon all support built-in Ethernet link aggregation. SAF Tehnika has designed a proprietary microwave Ethernet link aggregation mechanism. It was designed along the guidelines of the 802.3ad protocol and complies with its provisions. While the main enhancement specifically for microwave radio link aggregation is a proprietary control protocol, it takes into account specific properties of the microwave link such as: link capacity, received signal level, radial MSE, LDPC stress etc.

The Integra and Integra S radios support link bonding which works on Layer 1 and aggregates two parallel links capacity utilizing a single Ethernet connection e.g. single MAC to MAC or IP to IP connection may be used.
2. Link aggregation types within different SAF products

- **Built-in link aggregation:**
  - CFIP Phoenix M 2+0 utilizes link bonding, the method which can perform the link aggregation with one pair of MAC addresses.
    - This type of aggregation is based at the modem level which uses frame aggregation (link bonding).
  - With the Integra or Integra S radios you can setup 2+0 link bonding using various interconnection schemes. Please refer to Installation Manual.
  - With the CFIP Lumina - you can setup a 2+0 configuration using at least one pair of four port external switches and these switches are not involved in link aggregation.
  - With the CFIP Phoenix/Marathon radios, you can setup 2+0, 3+0 and 4+0 configuration. Basic external switches are required for interconnecting management traffic.

- **Link aggregation/balancing using external equipment:**
  - With the CFIP Lumina radio, you can setup n+0 configuration using external switches to achieve link aggregation or routers to achieve load balancing. *
  - With the Integra, Integra S, Integra W and Integra WS radios you can setup n+0 configuration using external switches to achieve link aggregation or routers to achieve load balancing. *
  - With the CFIP Phoenix/Marathon radios you can setup n+0 configuration using external switches to achieve link aggregation or routers to achieve load balancing. *
  - With the CFIP-106/108 FODU and SAF Freemile radios you can setup n+0 load balancing with external switches. Note: this will be load balancing, not link aggregation.

* The number of ports depend on desired LAG method
3. Table of aggregation types available with SAF products

<table>
<thead>
<tr>
<th>Product name</th>
<th>Layer 1</th>
<th>Layer 2</th>
<th>Layer 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Internal</td>
<td>External</td>
<td>Internal</td>
</tr>
<tr>
<td>Integra and Integra S</td>
<td>X</td>
<td>X*</td>
<td>-</td>
</tr>
<tr>
<td>Integra W and Integra WS</td>
<td>-</td>
<td>X*</td>
<td>-</td>
</tr>
<tr>
<td>CFIP Lumina 2 LAN ports</td>
<td>-</td>
<td>X*</td>
<td>X</td>
</tr>
<tr>
<td>CFIP Lumina 1 LAN port</td>
<td>-</td>
<td>X*</td>
<td>-</td>
</tr>
<tr>
<td>CFIP Phoenix M</td>
<td>X</td>
<td>X*</td>
<td>X</td>
</tr>
<tr>
<td>CFIP PhoenixX</td>
<td>-</td>
<td>X*</td>
<td>X</td>
</tr>
<tr>
<td>CFIP Marathon</td>
<td>-</td>
<td>X*</td>
<td>X</td>
</tr>
<tr>
<td>SAF Freemile 17/24</td>
<td>-</td>
<td>X*</td>
<td>-</td>
</tr>
<tr>
<td>SAF Freemile 5.8GE</td>
<td>-</td>
<td>X*</td>
<td>-</td>
</tr>
</tbody>
</table>

Layer 1 - Link bonding, any devices (router, switch, PC) can be connected;
Layer 2 - Link aggregation like LACP or load balancing by VLANs. Available with both Layer 2 and Layer 3 switches
Layer 3 - Load balancing - IP based. Available with routers and some Layer 3 switches.

* - In most cases it is not used in Layer 2, 3 switches or routers however it is possible.

There are other types of load balancing or aggregation based on higher layers of OSI.
4. Options and considerations for link aggregation

a. Splitters, couplers, OMT, branching system

**Couplers and splitters** are passive devices for dividing a microwave signal, which allows combining the signal of one radio with another radio into a single path and provides a single polarized coupling. The microwave signal can be divided into various proportions, for example 1:6 (asymmetrical) or 3:3 (symmetrical).

An **OMT** or **Orthomode transducer** is a passive device for filtering polarization from/to circular waveguide paths.

A standard SAF radio adapted coupler and OMT can be combined to connect 4 radios to a single antenna.

<table>
<thead>
<tr>
<th>Standard OMT + coupler</th>
<th>Compact hybrid combiner OMT + coupler</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Standard OMT + coupler" /></td>
<td><img src="image2.png" alt="Compact hybrid combiner OMT + coupler" /></td>
</tr>
</tbody>
</table>

**Outdoor Branching Unit**

Multiple radios can be connected to an antenna by using circulators and filters, which can be used either indoor (for all-indoor application) or outdoor. Frequency channel branching systems can allow connecting multiple radios to single antenna with minimal attenuation.
Comparison for various attenuations:

<table>
<thead>
<tr>
<th>Solution</th>
<th>Attenuation per port</th>
</tr>
</thead>
<tbody>
<tr>
<td>OMT</td>
<td>~ 0.5 dB</td>
</tr>
<tr>
<td>Symmetrical 3dB coupler</td>
<td>~ 3.5 dB</td>
</tr>
<tr>
<td>Asymmetrical 6dB coupler</td>
<td>Port1: ~1.8 dB, Port2: ~7.2 dB</td>
</tr>
<tr>
<td>OBU</td>
<td>~ 1.5 dB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Total attenuation with OBU, per radio</th>
<th>Total attenuation with coupler, per radio</th>
</tr>
</thead>
<tbody>
<tr>
<td>4+0 in single polarization</td>
<td>~ 1.5 dB per radio</td>
<td>~ 7 dB</td>
</tr>
<tr>
<td>4+0 with dual pol antenna</td>
<td>~ 1 dB per radio</td>
<td>~ 3.5 dB</td>
</tr>
</tbody>
</table>

Connection via flexible waveguide

Alternatively, a 4+0 system can be attached to any dual-polarization antenna with standard flanges by using external stand-alone couplers and waveguides.
b. Capacity and link options

In many cases the target capacity is 1Gbps, which is built from multiple parallel links. Below is a table for different options of achieving close to 1Gbps capacity with CFIP product series equipment.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Total capacity</th>
<th>Total BW</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>3+0 at 56MHz 256QAM</td>
<td>3x 334 = 1002 Mbps</td>
<td>168 MHz</td>
<td></td>
</tr>
<tr>
<td>4+0 at 56MHz 64QAM</td>
<td>4x 241 = 964 Mbps</td>
<td>224 MHz</td>
<td>Best system gain for longer distances or smaller antennas</td>
</tr>
<tr>
<td>4+0 at 40MHz 256QAM</td>
<td>4x 248 = 992 Mbps</td>
<td>160 MHz</td>
<td></td>
</tr>
<tr>
<td>4+0 at 50MHz 128QAM</td>
<td>4x 249 = 996 Mbps</td>
<td>200 MHz</td>
<td></td>
</tr>
<tr>
<td>4+0 at 56MHz 256QAM</td>
<td>4x 360 = 1440 Mbps</td>
<td>224 MHz</td>
<td></td>
</tr>
</tbody>
</table>

With the CFIP PhoeniX M system there is possibility to build radio links with mixed payload.

Example capacities with Integra

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Total capacity</th>
<th>Total BW</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2+0 at 60MHz 1024QAM Integra/Integra-S</td>
<td>2x 474 = 948 Mbps</td>
<td>120MHz</td>
<td></td>
</tr>
<tr>
<td>2+0 at 80MHz 256QAM Integra-W/Integra-WS</td>
<td>2x 514 = 1028 Mbps</td>
<td>160MHz</td>
<td>Very high system gain for link budget at 1Gbps *</td>
</tr>
</tbody>
</table>

* With external aggregation only

Please contact SAF representative to get more details on capacity and link options.
5. Built-in configuration examples

5.1 CFIP Lumina

With the CFIP Lumina, the link aggregation in 2+0 mode allows utilizing up to 732 Mbps Ethernet Layer 2 throughput (256QAM @ 56MHz) by using independent frequency pair for each link. Link aggregation of 2+0 traffic distribution between two links is based upon source and destination MAC addresses of Ethernet packets. Link aggregation (2+0) requires multiple MAC to MAC address pair connections as a path since each connection is chosen based upon Ethernet frame’s source and destination MAC addresses. A sufficient diversity of MAC addresses is required to achieve maximum aggregate throughput. The CFIP Lumina 2+0 link aggregation features link and power redundancy. If link loses synchronization or any unit fails traffic will be rerouted to the active link.

Necessary equipment:

- Two CFIP Lumina links. Each CFIP Lumina FODU should have two Ethernet ports (optical or electrical)
- Two Gigabit Ethernet switches.
- In order to connect radios to single antenna you can use coupler or OMT. Alternatively, you can use two separate antennas (please see Chapter 4).

![Interconnection scheme for Lumina 2+0](image)

FODU1 and FODU2 are in the master link. FODU3 and FODU4 are in the slave link.
**Features:**

- Up to 732 Mbps
- Physical layer protection:
  - Protection of hardware failure
  - Radio protection
  - Modem protection
  - Ethernet protection
- Automatic reconfiguration to 1+0 (traffic rerouting) in case of:
  - Synchronization loss of master link
  - Synchronization loss of slave link
  - Hardware failure of any CFIP Lumina FODU
  - Power supply failure
- Average switchover time 100ms

If the modulation of one link is downshifted, modulation on the other link will be aligned to the same configuration.

**5.2 CFIP PhoeniX**

The CFIP Phoenix has built-in link aggregation of 2+0, 3+0 and 4+0 modes. The modes allow the utilization of up to 1Gbps Ethernet Layer 2 throughput (256QAM @ 56MHz) by using independent frequency pair for each link.

Optional CFIP PhoeniX IDU (P/N S0GIP*11) is equipped with the power protection port. It provides redundancy for the internal power board, external power supply and power cables.

**Necessary equipment:**

- From four up to eight CFIP Phoenix IDU/ODU pairs.
- Two Gigabit Ethernet switches with at least 4 ports.
- OMT and/or couplers (please see Chapter 4).
Interconnection scheme for CFIP PhoeniX 2+0
IDU1 and IDU2 are in the master link. IDU3 and IDU4 are in the slave link.

Interconnection scheme for CFIP PhoeniX 4+0
IDU1 and IDU2 are in the master link. All other links are slave links.
5.3 Sample configuration with CFIP Phoenix M

CFIP ODU can utilize adapted mounting and hybrid combiner. A hybrid combiner consists of a built-in OMT with couplers attached to each polarization.

5.4 Integra, Integra S

The Integra/Integra-S’s 2+0 aggregation (link bonding) provides ACM-aware bonding. The ACM-aware bonding of the user available capacities take two parallel links, and each will use an individual frequency pair. Traffic is split per-frame over two links on the modem level.

Aggregation is not based on MAC-MAC connections. Single MAC address (e.g. router) can be used.

If any (master or slave) link synchronization goes down, switching to a working link is hitless. Two Integra or Integra-S FODUs are required. In the case of the Integra-S OMT, a dual-polarized antenna or coupler can be used.

**Necessary equipment for Integra 2+0**

1. 4 Integra/Integra-S FODUs – 2 low side, 2 high side
2. 2 or 4 SFP modules and appropriate FO cables (multi-mode or single mode) for Integra interconnection (depending on chosen interconnection scheme)
3. Electrical or optical Ethernet cables for user traffic (depending on chosen interconnection scheme)
4. In case of Integra-S – an additional 2 or 4 antennas and OMT/couplers
Interconnection schemes

There are 4 possible interconnection schemes:

**Scheme 1**

1. Optical cable between the LAN2 (optical) ports on both units. Mandatory in all 4 schemes.
2. Electrical Ethernet cable (1000Base-T) between PoE injector’s (#1) DATA+PWR port and LAN1 (electrical) port of Slave Integra/Integra-S FODU. Both data and power are carried, therefore total length of cables #2, #3 and #4 combined should not exceed 100m.
3. Electrical Ethernet cable (1000Base-T) between PoE injector’s (#2) DATA+PWR port and LAN1 (electrical) port of Master Integra/Integra-S FODU. Both data and power are carried, therefore total length of cables #2, #3 and #4 combined should not exceed 100m.
4. Electrical Ethernet cable (1000Base-T) between PoE injectors’ (#1 and #2) DATA ports. Provides management access to Slave Integra/Integra-S FODU. Total length of cables #2, #3 and #4 combined should not exceed 100m.
5. Optical fiber cable between LAN3 (optical) port of Master or Slave Integra/Integra-S FODU and CPE for both traffic and management traffic.

Advantages: An external switch is not required; length of optical cable for traffic/management up to 10km.
Scheme 2

1. Optical cable between the LAN2 (optical) ports on both units. Mandatory in all 4 schemes.
2. Cable for powering Slave Integra/Integra-S FODU. You can use 2-wire power cable with DC power adapter (P/N D0ACPW01) or standard Ethernet cable with PoE injector. Depending on power consumption cable length can be extended up to 700m. Refer to chapter RJ-45 port for details.
3. Electrical Ethernet cable (1000Base-T) between PoE injector’s (#2) DATA+PWR port and LAN1 (electrical) port of Master Integra/Integra-S FODU. Both data and power are carried, therefore total length of cables #3 and #5 combined should not exceed 100m.
4. Optical fiber cable between LAN3 (optical) ports on both units. Provides management access to Slave Integra/Integra-S FODU.
5. Electrical Ethernet cable (1000Base-T) between PoE injector’s (#1 or #2) DATA port and CPE or both traffic and management traffic. Total length of cables #3 and #5 combined should not exceed 100m.

Advantages: An external switch is not required; optical cables used only for interconnection between both Integra/Integra-S FODUs; only two cables installed between Integra/Integra-S FODUs and indoor facility.
Scheme 3

1. Optical cable between the LAN2 (optical) ports on both units. Mandatory in all 4 schemes.
2. Cable for powering Slave Integra/Integra-S FODU. You can use 2-wire power cable with DC power adapter (P/N D0ACPW01) or standard Ethernet cable with PoE injector. Depending on power consumption cable length can be extended up to 700m. Refer to chapter RJ-45 port for details.
3. Cable for powering Master Integra/Integra-S FODU. You can use 2-wire power cable with DC power adapter (P/N D0ACPW01) or standard Ethernet cable with PoE injector. Depending on power consumption cable length can be extended up to 700m. Refer to chapter RJ-45 port for details.
4. Optical cable between the LAN3 (optical) port of the Slave Integra/Integra-S FODU and external switch. Provides management access to Slave Integra/Integra-S FODU.
5. Electrical Ethernet cable (1000Base-T) between the external switch and CPE for both traffic and management traffic.
6. Optical cable between the LAN3 (optical) port of Master Integra/Integra-S FODU and external switch for both traffic and management traffic.

Advantages: Solution provides greatest cable length for powering Integra/Integra-S and length of optical cable for traffic/management can be up to 10km. For details on power cable length refer to chapter RJ-45 port.
Scheme 4

1. Optical cable between the LAN2 (optical) ports on both units. Mandatory in all 4 schemes.
2. Electrical Ethernet cable (1000Base-T) between PoE injector’s (#1) DATA+PWR port and LAN1 (electrical) port of the Slave Integra/Integra-S FODU. Both data and power are carried, therefore total length of cables #2 and #6 combined should not exceed 100m.
3. Electrical Ethernet cable (1000Base-T) between PoE injector’s (#2) DATA+PWR port and LAN1 (electrical) port of the Master Integra/Integra-S FODU. Both data and power are carried, therefore total length of cables #3 and #4 combined should not exceed 100m.
4. Electrical Ethernet cable (1000Base-T) between the PoE injector’s (#1) DATA port and external switch. The total length of cables #3 and #4 combined should not exceed 100m.
5. Electrical Ethernet cable (1000Base-T) between the external switch and CPE or both traffic and management traffic.
6. Electrical Ethernet cable (1000Base-T) between the PoE injector’s (#2) DATA port and external switch. The total length of cables #2 and #6 combined should not exceed 100m.

Advantages: Only a single optical cable required; only two cables installed between Integra/Integra-S FODUs and indoor facility.
6. Link aggregation using external equipment

Some network operators would like to use their own link aggregation methods based on LACP as well other methods. The most frequently ignored issue is related to putting CFIP management inside one of two balanced Ethernet paths. This is a violation because balancing logic does not expect any Ethernet device in-between two aggregated switches. As a result, traffic will go through, but management access to each CFIP Lumina will be available only from 50% of MAC addresses – might be available from one PC but not available from another, which is not predictable.

Following are some examples showing how to implement link aggregation, or load balance, using external switches and routers and ensure stable management access to CFIP products.

6.1 Link aggregation using external switches via LACP (or PAgP) protocol with MAC or IP address hashing on CISCO switches.

After the switch CRC hash calculation, based on its chosen method SA-DA, SA or DA, the switch will send packets using a chosen path. Along with traffic, the CFIP management packets can be routed along paths where the requested CFIP unit doesn’t exist. This may cause inaccessibility to CFIP management. To avoid this problem, it is recommend that a two a port CFIP Lumina or CFIP PhoeniX, where you can separate data traffic from management traffic using VLANs, is used.

Below is an interconnection example for 2+0 Lumina with 2 Ethernet ports and external managed switches.
In this setup 2-port (electrical) Luminas and CISCO 3750 switches are used. Each CFIP Lumina is configured to trunk traffic on LAN port number 4 and Lumina radios management is on LAN port number 3.

<table>
<thead>
<tr>
<th>VLAN configuration table</th>
</tr>
</thead>
<tbody>
<tr>
<td>VLAN Nr.</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>Default VLAN</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>Select/De-select all VLAN(-s)</td>
</tr>
<tr>
<td>Delete VLAN(-s)</td>
</tr>
<tr>
<td>Add new VLAN</td>
</tr>
<tr>
<td>Nr.:</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>System returned:</td>
</tr>
</tbody>
</table>

VLAN configuration on Lumina

Note: Traffic is tagged on external switches. VLAN100 is management and VLAN200 is data traffic. VLAN1 will pass untagged traffic which is required for communication between external switches. You also can use Lumina radios built-in switch to tag Ethernet traffic (data and management traffic).

In such configuration it is important to configure CISCO switches properly. As configuration is the same on all four units and management VLAN is trunked via CFIP Lumina WAN port and external switches, a network loop on the management VLAN will be created. Utilizing the spanning tree protocol (PVST – CISCO proprietary protocol) will block one of four ports to avoid network loop, and management still will be accessible on all four units. Other switches are using MSTP protocol to avoid Ethernet loops with Multiple VLANs (configuration for MSTP is described below).

The link between two CISCO switches is considered working from the switch perspective when the port condition is “UP”. In case of synchronization loss in the Lumina link which connects two switches, Ethernet ports will be still in the “UP” state and switches will consider that the link is working, thereby continuing to send the traffic which will be dropped on the Lumina device. LACP protocol can detect broken the link even if Ethernet port is “UP” and redirect all traffic to another path, however, this procedure might take more than 1 minute with slow LACP. Aggregation restoration is more or less dependent on external switches in the case of radio sync loss.
The CFIP Lumina, Marathon and PhoeniX products have a “Link State Propagation” feature which allows shutting down specified LAN ports if synchronization loss events occur. In this case, CISCO switches will immediately detect that the port switched to the “DOWN” state and the LACP protocol will redirect traffic to another path. This scenario is much faster than the broken link detection by LACP – less than 1 sec, compared to around 60 to 90 seconds by slow LACP.

The link state propagation configuration is available in Configuration -> Ethernet configuration Web GUI page.

![Link state propagation configuration](image)

**Explanation:**

- **LAN auto recovery** (0..600) sec – synchronization loss timeout after which port is reenabled even if link synchronization is still lost, otherwise timeout is ignored.

- **SyncLoss keepalive timeout** (0..10) sec – LAN port shutdown timeout after synchronization loss and synchronization recovery events.

- **LSP startup timeout** (0..3600) sec – LSP activity timeout after management CPU start up and configuration script execution. During this period synchronization events are ignored.

- **SNMP traps** – SNMP trap will be sent if enabled.

**Configuration of CISCO switches:**

```bash
! spanning-tree mode pvst
no spanning-tree optimize bpdu transmission
spanning-tree extend system-id
!
interface Port-channel1
  switchport trunk encapsulation dot1q
  switchport trunk allowed vlan 200
  switchport mode trunk
!
```
interface GigabitEthernet2/0/1
  switchport trunk encapsulation dot1q
  switchport trunk allowed vlan 200
  switchport mode trunk
  channel-group 1 mode active
!
interface GigabitEthernet2/0/2
  switchport trunk encapsulation dot1q
  switchport trunk allowed vlan 200
  switchport mode trunk
  channel-group 1 mode active
!
interface GigabitEthernet2/0/3
  switchport access vlan 200
  switchport mode access
!
interface GigabitEthernet2/0/4
  switchport access vlan 100
  switchport mode access
!
interface GigabitEthernet2/0/5
  switchport trunk encapsulation dot1q
  switchport trunk allowed vlan 100
  switchport mode trunk
!
interface GigabitEthernet2/0/6
  switchport trunk encapsulation dot1q
  switchport trunk allowed vlan 100
  switchport mode trunk
!

Explanation:

interface Port-channel1 – Specifies EtherChannel number

Interfaces ge0/1 – 0/2 are used to trunk aggregated traffic to other peer thru Lumina radios.
Interface ge0/3 – is network cloud (lots of SA-DA MACs)
Interface ge0/4 – is for management PC
Interfaces ge0/5 – 0/6 are used to trunk management data to Lumina.

There is no limitation to the number of aggregated parallel links, it depends on the number of external switches.

The same configuration of Lumina radios and switches should be used in case of link aggregation, which is based on IP hashing. You will need to add “port-channel load-balance src-dst-ip” in to CISCO global configuration.
6.2 Link aggregation using external switches via LACP protocol with MSTP enabled on external switch.

By default, CISCO switches are using a proprietary PVST protocol. This protocol works very well without special “fine tuning” of STP (Spanning-Tree Protocol). Other brands have MSTP (Multiple Spanning-Tree protocol) which requires “fine tuning” for correct STP behavior. Important properties are: setup region name and revision, instances per VLAN, BPDU filter must be applied on aggregated port (not physical interface), correct port priority and path costs for aggregated ports.

Configuration of MSTP:

```plaintext
spanning-tree mode mst
no spanning-tree optimize bpdu transmission
spanning-tree extend system-id

spanning-tree mst configuration
name REGION <- name for MST region, revision is 0 by default
instance 1 vlan 100 <- Instance for management VLAN
instance 2 vlan 200 <- Instance for traffic VLAN

Instance 0 (MST00) is enabled by default. This instance contains all untagged service packets for correct communication between external switches.

Configuration of aggregation interface:

interface Port-channel1 <- Etherchannel interface (LAG)
switchport trunk allowed vlan 200 <- Command to allow only traffic VLAN
switchport mode trunk
flowcontrol send off
spanning-tree bpdufilter enable <- Command to enable BPDU filter
spanning-tree port-priority 0 <- Command to set port priority for Etherchannel interface (0 - highest)

Please check the status of STP after successful configuration, the aggregation port must be in “forwarding” state.

You need to check STP behavior on the external switches after correct configuration. The aggregation port must be in “forwarding” state.
6.3 Load balancing based on per packet or per destination using routers

Another method is to use routers and load balancing between nodes. On CISCO routers there are two ways:

**per-packet** - load balancing allows the router to send data packets over successive equal-cost paths without regard to individual destination hosts or user sessions. Path utilization is good, but packets destined for a given destination host might take different paths and might arrive out of order.

**per-destination** - load balancing allows the router to use multiple, equal-cost paths to achieve load sharing. Packets for a given source-destination host pair are guaranteed to take the same path, even if multiple, equal-cost paths are available. Traffic for different source-destination host pairs tend to take different paths.

The “per-packet” method which can be used to load balance with one source IP and destination IP will be explained further on.

This is interconnection example for 2+0 Lumina with one or two Ethernet ports and CISCO routers.
Configuration of CISCO routers:

Router Nr.1:

!  
ip cef  
ip cef load-sharing algorithm original  
!  
interface FastEthernet0/0  
ip address 192.168.20.2 255.255.255.0  
ip load-sharing per-packet  
duplex auto  
speed auto  
!  
interface FastEthernet0/1  
ip address 192.168.30.2 255.255.255.0  
ip load-sharing per-packet  
duplex auto  
speed auto  
!  
interface FastEthernet0/1/0  
switchport access vlan 20  
!  
interface Vlan20  
ip address 192.168.205.1 255.255.255.0  
!  
!  
ip route 0.0.0.0 0.0.0.0 FastEthernet0/0 192.168.20.1  
ip route 0.0.0.0 0.0.0.0 FastEthernet0/1 192.168.30.1  
ip route 192.168.205.0 255.255.255.0 FastEthernet0/0 192.168.20.1  
ip route 192.168.205.0 255.255.255.0 FastEthernet0/1 192.168.30.1  
ip route 192.168.205.0 255.255.255.0 Vlan20  
!

Router Nr.2:

!  
ip cef  
ip cef load-sharing algorithm original  
!  
interface FastEthernet0/0  
ip address 192.168.20.1 255.255.255.0  
ip load-sharing per-packet  
duplex auto  
speed auto  
!  
interface FastEthernet0/1  
ip address 192.168.30.1 255.255.255.0  
ip load-sharing per-packet  
duplex auto  
speed auto  
!
interface FastEthernet0/0/1
  switchport access vlan 20
!
interface Vlan20
  ip address 192.168.206.1 255.255.255.0
  !
  ip route 0.0.0.0 0.0.0.0 FastEthernet0/0 192.168.20.2
  ip route 0.0.0.0 0.0.0.0 FastEthernet0/1 192.168.30.2
  ip route 192.168.206.0 255.255.255.0 FastEthernet0/0 192.168.20.2
  ip route 192.168.206.0 255.255.255.0 FastEthernet0/1 192.168.30.2
  ip route 192.168.206.0 255.255.255.0 Vlan20
!

CEF switching (Layer3) requires higher performance of equipment than Layer2 link aggregation methods. Please check the CISCO routers CEF performance by this URL: http://www.cisco.com/web/partners/downloads/765/tools/quickreference/routerperformance.pdf

6.4 Load balancing based on VLANs with protection

Load balancing with VLANs can be configured on any CFIP device or Integra S/W with one Ethernet port and any switch which has VLANs and Spanning-tree per VLAN (PVST, MSTP). Load balance also provides protection in case of one link fail.

spanning-tree mode mst <- PVST can be used instead of MST
no spanning-tree optimize bpdu transmission
spanning-tree extend system-id
!
spanning-tree mst configuration
  name REGION
  instance 1 vlan 100
  instance 2 vlan 200
  instance 3 vlan 300
!
vlan 100,200,300
!
interface FastEthernet0/1
  switchport access vlan 100
  switchport mode access
!
interface FastEthernet0/13
  switchport trunk allowed vlan 200,300
  switchport mode trunk
!
interface FastEthernet0/17
  switchport trunk allowed vlan 100,200,300
  switchport mode trunk
  spanning-tree vlan 300 port-priority 0 <- port priority for VLAN 300
!
interface FastEthernet0/18
  switchport trunk allowed vlan 100,200,300
  spanning-tree vlan 200 port-priority 0 <- port priority for VLAN 200

Interface Fa0/1 - port for management PC
Interface Fa0/13 – port where traffic is already tagged with VLANs 200,300
Interface Fa0/17 – port to CFIP device with management and traffic VLANs
Interface Fa0/18 – port to CFIP device with management and traffic VLANs

VLAN 200 will be blocked on interface Fa0/17 and VLAN will be blocked on interface Fa0/18 by STP in such configuration. VLAN 300 will pass through link “1” and VLAN 200 will pass through link “2”. Also management VLAN will be blocked to avoid loop and all CFIP devices will be accessible.
6.5 Link aggregation using CISCO switches and LACP (or PgAP) aggregation method with Integra S radios.

After the CISCO switch CRC hash calculation, based on chosen method SA-DA, SA or DA (or IPs), the switch will send packets using one or another physical port, which is included in the Port-Channel interface (virtual interface which contains bunch on physical interfaces). Along with traffic, the Integra S management packet can be routed to one or another path where the requested radio unit doesn’t exist, this may cause the inaccessibility of radio’s management. To avoid this problem, we recommend using two ports of radios where you can separate data traffic from management traffic using VLANs.

For example: PoE ports (electrical) at each radio will be used for device management with power only and LAN2 (fiber ports) will be used as LACP ports.

As all management ports will be connected to the same broadcast domain, Ethernet loop will occur. To avoid loop, STP will block one of the management ports in CISCO switch, if STP is enabled. Which port will be disabled depends on STP configuration. Of course it is not necessary to connect all management ports to CISCO, but it will additional protection to the management ports in case if one (or more) unit failure.

Note: Ethernet loop will not occur on LACP (Port-Channel) ports.
Switch A configuration and status output:

```bash
interface Port-channel1
  port-type nni
!
!
interface GigabitEthernet0/1
  port-type nni
  switchport trunk allowed vlan 200
  switchport mode trunk
  media-type rj45
!
interface GigabitEthernet0/2
  port-type nni
  switchport trunk allowed vlan 200
  switchport mode trunk
  media-type rj45
!
interface GigabitEthernet0/3
  port-type nni
  channel-group 1 mode active
!
interface GigabitEthernet0/4
  port-type nni
  channel-group 1 mode active
!
```

Logical scheme and CISCO (ME3400) configuration example
tw01-Main#show spanning-tree

VLAN0001
Spanning tree enabled protocol rstp
Root ID  Priority  32769
        Address  108c.cf8d.7800
        Cost  3
        Port  56 (Port-channel1)
        Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
Bridge ID  Priority  32769 (priority 32768 sys-id-ext 1)
        Address  108c.cf8d.8700
        Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
        Aging Time  300 sec

Interface       Role  Sts  Cost       Prio.Nbr  Type
--------------------- ---- ---- ------- -------------------------
-  Po1            Root  FWD 3       128.56   P2p

VLAN0200
Spanning tree enabled protocol rstp
Root ID  Priority  32968
        Address  108c.cf8d.7800
        Cost  4
        Port  1 (GigabitEthernet0/1)
        Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
Bridge ID  Priority  32968 (priority 32768 sys-id-ext 200)
        Address  108c.cf8d.8700
        Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
        Aging Time  300 sec

Interface       Role  Sts  Cost       Prio.Nbr  Type
--------------------- ---- ---- ------- -------------------------
-  Gi0/1          Root  FWD 4       128.1    P2p
-  Gi0/2          Altn BLK 4       128.2    P2p

tw01-Main#show lacp neighbor
Flags:  S - Device is requesting Slow LACPDUs
        F - Device is requesting Fast LACPDUs
        A - Device is in Active mode       P - Device is in Passive mode

Channel group 1 neighbors

Partner's information:

<table>
<thead>
<tr>
<th>Port</th>
<th>Flags</th>
<th>LACP port</th>
<th>Priority</th>
<th>Dev ID</th>
<th>Age</th>
<th>key</th>
<th>Key</th>
<th>Number</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gi0/3</td>
<td>SA</td>
<td>32768</td>
<td>108c.cf8d.7800</td>
<td>12s</td>
<td>0x0</td>
<td>0x1</td>
<td>0x104</td>
<td>0x3D</td>
<td></td>
</tr>
<tr>
<td>Gi0/4</td>
<td>SA</td>
<td>32768</td>
<td>108c.cf8d.7800</td>
<td>20s</td>
<td>0x0</td>
<td>0x1</td>
<td>0x105</td>
<td>0x3D</td>
<td></td>
</tr>
</tbody>
</table>
Switch B configuration and status output:

interface Port-channel1
  port-type nni
!
interface GigabitEthernet0/1
  port-type nni
  switchport trunk allowed vlan 200
  switchport mode trunk
  media-type rj45
!
interface GigabitEthernet0/2
  port-type nni
  switchport trunk allowed vlan 200
  switchport mode trunk
  media-type rj45
!
interface GigabitEthernet0/3
  port-type nni
  channel-group 1 mode active
!
interface GigabitEthernet0/4
  port-type nni
  channel-group 1 mode active
!
tw3-main#show lacp neighbor
Flags:  S - Device is requesting Slow LACPDUs
        F - Device is requesting Fast LACPDUs
        A - Device is in Active mode       P - Device is in Passive mode

Channel group 1 neighbors

Partner's information:

<table>
<thead>
<tr>
<th>Port</th>
<th>Flags</th>
<th>Priority</th>
<th>Dev ID</th>
<th>Age</th>
<th>key</th>
<th>Key</th>
<th>Number</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gi0/3</td>
<td>SA</td>
<td>32768</td>
<td>108c.cf8d.8700</td>
<td>10s</td>
<td>0x0</td>
<td>0x1</td>
<td>0x104</td>
<td>0x3D</td>
</tr>
<tr>
<td>Gi0/4</td>
<td>SA</td>
<td>32768</td>
<td>108c.cf8d.8700</td>
<td>7s</td>
<td>0x0</td>
<td>0x1</td>
<td>0x105</td>
<td>0x3D</td>
</tr>
</tbody>
</table>

tw3-main#show spanning-tree

VLAN0001
Spanning tree enabled protocol rstp
Root ID  Priority    32769
        Address     108c.cf8d.7800
This bridge is the root
Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec

Bridge ID  Priority    32769  (priority 32768 sys-id-ext 1)
        Address     108c.cf8d.7800
Hello Time   2 sec  Max Age 20 sec  Forward Delay 15 sec
Aging Time   300 sec

Interface           Role Sts Cost      Prio.Nbr Type
------------------- ---- ----- -------- -------------             
                    -     FWD 3         128.56   P2p
VLAN0200
Spanning tree enabled protocol rstp
Root ID  Priority  32968
Address  108c.cf8d.7800
This bridge is the root
Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec

Bridge ID  Priority  32968  (priority 32768 sys-id-ext 200)
Address  108c.cf8d.7800
Hello Time  2 sec  Max Age 20 sec  Forward Delay 15 sec
Aging Time  300 sec

<table>
<thead>
<tr>
<th>Interface</th>
<th>Role</th>
<th>Sts</th>
<th>Cost</th>
<th>Prio.Nbr</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gi0/1</td>
<td>Desg</td>
<td>FWD</td>
<td>4</td>
<td>128.1</td>
<td>P2p</td>
</tr>
<tr>
<td>Gi0/2</td>
<td>Desg</td>
<td>FWD</td>
<td>4</td>
<td>128.2</td>
<td>P2p</td>
</tr>
</tbody>
</table>

Configuration of radios is the same in all units:

LAN1 – The management port to be used as the trunk for management VLAN200.
LAN2 – LACP port as access for LACP BPDUs with traffic.

Note: D – VLAN disabled, T – port is in trunk mode (tagged), U – port is in access mode (untagged).
6.6 Link aggregation using CISCO switches and LACP (or PgAP) aggregation method with Integra-W radios.

There are two scenarios:
1. User traffic is not separated from management traffic with VLANs in the network.
2. User traffic is separated from management traffic with VLANs in the network.

Since the Integra-W internal switch is not configurable, it is not possible to separate management traffic with VLANs within the radio link. It is recommend using Out of Band management software where two ports of radios are used – MNG port for management, LAN port for traffic. In the following scenario both Integra-W MNG and LAN ports are connected to the CISCO 3750g switches.

The Integra-W link with out-band management implements two Ethernet connections – one for management traffic and the second for user traffic. Since user traffic and management circuits are parallel, an Ethernet loop will occur. To avoid the loop, management on WAN interfaces has to be disabled by entering this command in CLI "modem management 0". Thereby management
traffic will only pass through the wireless link via the user traffic connection egressing the MNG port.

System / Console

SAN
- User configuration commands
disable
- Firmware update and information
disable
- CLI usage
disable
- License commands
disable
- System supplies
- Event / Performance log control and configuration
disable
- Admin commands
disable
- Network functionality
disable
- Product toolbox
disable
- Radio commands
disable
- System configuration
- System configuration

modern management

SAF: Management capacity - 0 Mbps

modem management 0

Disable management on WAN interfaces

Logical scheme and CISCO (Catalyst 3750G) configuration example with management on WAN interfaces disabled and VLANs enabled

Link aggregation/bonding and load balancing with SAF products
After the CISCO switch CRC hash calculation, based on the chosen method SA-DA, SA or DA (or IPs), the switch will send packets using one or another physical port which is included in Port-Channel interface (virtual interface which contains bunch on physical interfaces). The following load-balance hashing methods are available:

- Source or Destination MAC addresses (Load distribution is based on the source-host or destination-host MAC address of the incoming packet)
- Source XOR Destination MAC addresses (Load distribution is based on the source-and-destination host-MAC address)
- Source or Destination IP addresses (Load distribution is based only on the source-host or destination-host IP address)
- Source XOR Destination IP addresses (Load distribution is based on the source-and-destination host-IP address)

In the following example, the Source XOR Destination MAC addresses method is used.

Note: Ethernet loop will not occur on LACP (Port-Channel) ports.

Another important thing to be taken into account is the monitoring status of the Ethernet link. The link between two CISCO switches is considered working from the switch perspective when the port condition is “UP”. In case of synchronization loss in the Integra-W link which connects two switches, Ethernet ports will be still in “UP” state and switches will consider that the link is working, thereby continuing to send the traffic which will be dropped on the Integra-W device. LACP protocol can detect broken link even if Ethernet port is “UP” and redirect all traffic to another path. However, this procedure might take more than 1 minute with slow LACP. Aggregation restoring is more or less depended on external switches in case of radio sync loss.

**Configuration of CISCO switches without VLAN configuration:**

```plaintext
! port-channel load-balance src-dst-mac
! spanning-tree mode pvst
spanning-tree extend system-id
!
! interface Port-channel1
   description Integra Link
!
interface GigabitEthernet2/0/1
   channel-group 1 mode active
!
interface GigabitEthernet2/0/2
   channel-group 1 mode active
!
interface GigabitEthernet2/0/3
   description Management Radio
!
interface GigabitEthernet2/0/4
   description Management Radio
!
interface GigabitEthernet2/0/5
   description Traffic + Mng
```
Note: This scenario is meant for untagged traffic. VLANs are not configured on the CISCO switch interfaces. All incoming traffic passes the link and management traffic is not isolated in separate VLANs within the network.

Configuration of CISCO switches with VLAN configuration:

!  
port-channel load-balance src-dst-mac
!  
spanning-tree mode pvst
spanning-tree extend system-id
!  
interface Port-channel1
description Integra Link
switchport trunk encapsulation dot1q
switchport trunk allowed vlan 1,101-200,990
switchport mode trunk
!  
interface GigabitEthernet2/0/1
switchport trunk encapsulation dot1q
switchport trunk allowed vlan 1,101-200,990
switchport mode trunk
channel-group 1 mode active
!  
interface GigabitEthernet2/0/2
switchport trunk encapsulation dot1q
switchport trunk allowed vlan 1,101-200,990
switchport mode trunk
channel-group 1 mode active
!  
interface GigabitEthernet2/0/3
description Management Radio
switchport access vlan 990
switchport mode access
!  
interface GigabitEthernet2/0/4
description Management Radio
switchport access vlan 990
switchport mode access
!  
interface GigabitEthernet2/0/5
description Traffic + Mng
switchport trunk encapsulation dot1q
switchport trunk allowed vlan 1,101-200,990
switchport mode trunk
!
interface GigabitEthernet2/0/6
  description Management PC Port
  switchport access vlan 990
  switchport mode access
!
!
switch#show lacp neighbor
Flags:  S - Device is requesting Slow LACPDU
        F - Device is requesting Fast LACPDU
        A - Device is in Active mode       P - Device is in Passive mode

Channel group 1 neighbors

Partner's information:

<table>
<thead>
<tr>
<th>Port</th>
<th>Flags</th>
<th>Priority</th>
<th>Dev ID</th>
<th>Age</th>
<th>Admin key</th>
<th>Oper key</th>
<th>Port Number</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gi2/0/1</td>
<td>SA</td>
<td>32768</td>
<td>0013.c4df.4e00</td>
<td>14s</td>
<td>0x0</td>
<td>0x1</td>
<td>0x43</td>
<td>0x3D</td>
</tr>
<tr>
<td>Gi2/0/2</td>
<td>SA</td>
<td>32768</td>
<td>0013.c4df.4e00</td>
<td>21s</td>
<td>0x0</td>
<td>0x1</td>
<td>0x44</td>
<td>0x3D</td>
</tr>
</tbody>
</table>

Note: Traffic is tagged on external switches. VLAN990 is management and VLANs 101-200 are data traffic. VLAN1 will pass untagged traffic which is required for communication between external switches. Since Integra-W does not support VLANs, management traffic has to arrive untagged to the Integra-W management port. Therefore, the Integra-W management port is connected to CISCO Access port with management VLAN configured on it. Also you can use CISCO external switch to tag Ethernet traffic (data and management traffic) on specific interfaces.

Explanation:

interface Port-channel11 - specifies EtherChannel number.
channel-group 1 mode active - ties the physical interface to the Port-Channel 1 logical interface.

Interfaces ge2/0/1 – 2/0/2 are used to trunk aggregated traffic to other peer thru Integra-W radios.
Interface ge2/0/3 - is network cloud (lots of SA-DA MACs).
Interface ge2/0/4 - is for management PC.
Interfaces ge2/0/5 – 2/0/6 are used for management data to Integra-W.

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