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ALTO-based Broker-assisted Multi-domain Orchestration
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Abstract

Evolving networking scenarios (e.g., 5G) demand new multiple administrative domain (aka multi-domain) orchestration models. This document proposes a new broker-plane approach working on top of per-domain management and orchestration functions to coordinate the delivery of a multi-operator End-to-End Network Service (E2ENS). This proposed design resorts to the Application-Layer Traffic Optimization (ALTO) protocol to offer topology and resource information from different administrative domains. The ALTO services with the proposed protocol extension offer aggregated views on various types of resources contributing to a more simple and scalable solution.

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1. Introduction

Envisioned 5G network architectures and related service models consider broader cooperation between stakeholders in order to provide flexible multi-operator multi-domain services. These multi-provider orchestration operations will require the information exchange across Multi-domain Orchestrators (MdOs). The key information to be exchanged between MdOs includes the abstract network topology, resource availability (e.g., CPUs, Memory, and Storage) and capability (e.g., supported network functions).

This document presents a federation networking paradigm where a broker-plane works on top of the management and orchestration plane to assist and coordinate the creation of an End-to-End Network Service (E2ENS) spanning over multi-operator multi-domain networks. Our design resorts to the Application-Layer Traffic Optimization (ALTO) protocol [RFC7285] to address the lack of abstractions to discover and adequately represent in confidentiality-preserving fashion the resource and topology information from different administrative domains. Moreover, this draft introduces an extension to the ALTO base protocol for inter-domain connectivity information discovery.

2. Terminology

We use the following definitions, as established in [ETSI-NFV-DEF]:

Administrative Domain: Collection of systems and networks operated by a single organization or administrative authority.

Network Function (NF): Functional block within a network infrastructure that has well-defined external interfaces and well-defined functional behaviour.

Network Functions Virtualisation (NFV): The principle of separating network functions from the hardware they run on by using virtual hardware abstraction.

NF Forwarding Graph: (NFFG): Graph of logical links connecting NF nodes for the purpose of describing traffic flow between these network functions.

Network Service Orchestration (NSO): Function responsible for network service lifecycle management.

Resource Orchestration (RO): Function responsible for global resource management governance.

Our proof of concept implementation follows the architectural proposal of the 5GEx project [H2020.5GEX]. Some additional 5GEx terms commonly used in this document are defined below:

Domain Orchestrator (DO): Performs Resource Orchestration and/or Service Orchestration within the same administrative domain.

Multi-domain Orchestrator (MdO): Coordinates resource and/or service orchestration at multi-domain level, where multi-domain may refer to multiple DOs or multiple administrative domains.

Resource Topology (RT): Functional module that is responsible for keeping an updated global view of the underlying infrastructure topology exposed by DOs.

Service Graph (SG): A high-level data model for defining flexible network services (including traffic steering primitives).

Service Access Point (SAP): A named/tagged port supporting stitching (service to service, domain to domain, etc.)

3. Scope

Envisioned 5G scenarios are expected to work not only with heterogeneous technologies but also across different network operators. Many ongoing standardization activities and research projects are addressing the multi-provider multi-domain orchestration challenges under different approaches.

For example, within the IETF, [RFC8459] proposes a hierarchical Service Function Chaining (SFC) for multiple domains under the same administrative entity, and the document "Hybrid Hierarchical Multi-Domain SFC [DRAFT-HHSFC] describes SFC crossing different domains owned by various organizations or by a single organization with administration partitions. In the NFVRG, the draft "Multi-domain Network Virtualization" [DRAFT-MD-VIRT] envisions a complete E2E logical network as stitching services offered by multiple domains from multiple providers. Another initiative is the ETSI Industry Specification Group for Network Functions Virtualization (ETSI NFV ISG), the document [ETSI-NFV-IFA028] reports different NFV MANO architectural approaches with use cases related to network services provided using multiple administrative domains.

In case of research projects, [H2020.5GEX] [H2020-5G-TRANSFORMER] seek to integrate multiple administrations and technologies through the collaboration between operations. Other studies are envisioned to use a centralized approach, where each domain advertises its capabilities to a federation layer which will act as a broker [VITAL][T-NOVA]. The proposed architecture in [ICAF] allows the creation of cloud services from different administrative domains, however, it is not related to the provisioning of NFV-based cross-domain network services.

All such proposals described above envision the potential introduction of new business model approaches, including federation models [PPP-5:2013] among administrative domains. In this context, this document considers each network operator involved in the community advertises its abstracted capabilities (e.g., software/hardware resources, physical/virtual network functions, etc.) to a

broker (i.e., 3rd party). This broker, in its turn, provides or assists coordinate E2E network services spanning multi-domain networks.

4. Problem Statement and Challenges

The provision of a complete E2E network service requires chaining services provided by multiple network operators with multiple technologies. In this multi-domain environment, the orchestration process will require an advertisement mechanism through which individual domains can describe their capabilities, resources, and VNFs in an interoperable manner. Moreover, a discovery mechanism is also necessary so that source domains can obtain candidate domains (with the corresponding connectivity information) which can provide a part of the service and/or slice in an E2ENS requirement.

In order that the advertising and discovery process works in a proper way, a number of challenges can be identified:

Lack of Abstractions: Multiple vendors with heterogeneous technologies need an information model to adequately represent in confidentiality-preserving fashion the resource and topology information.

Scalability: Involves the distribution of topology and resource information in a peer-to-peer fashion (MdO-to-MdO). Multi-operator multi-domain environments where the information distribution is advertised in a peer-to-peer model scales linearly. It means more MdO interconnections one has, the more it "costs" to distribute.

Flexibility: Considers that a distributed approach does not allow domains without physical infrastructure (e.g., without BGP or BGP-LS) to advertise resource capabilities and networking resources. Such procedures consist in deploying and configuring physical peering points for these domains.

Complexity: Refers to the discovery mechanism to pre-select candidate domains, accounting for resources and capabilities, necessary for an E2E network service deployment. An intrinsic complexity exists in the process of assembling, logically organizing, and enabling abstraction views of different resources and capabilities in multi-domain scenarios.

5. Proposed Approach

The primary design goal for ALTO-based Broker-assisted Multi-domain Orchestration is to discover resource and topology information from different administrative domains involved in the federation, while also safeguarding the privacy and autonomy of every domain.

In the architectural proposal shown in Figure 1, a broker component is conceived to be working as coordinator of a set of MdOs. In particular, the broker-assisted design consists of the following key components: (i) Inter-domain Resource (IdR), (ii) Inter-domain Topology (IdT), and (iii) ALTO Server.

```
                              BROKER COMPONENT
              +--------------------------------------------+
              |                                            |
              |             +-----------------+            |
              |             |                 |            |
          XXXXXXXXXXXXXXXXXXX ALTO SERVER(s)  |            |
          X   |             |                 +            |
          X   |             +----------------+\            |
          X   |            /                   \           |
          X   |           /                     \          |
          X   |  +------+/+-------+     +---------------+  |
          X   |  | Inter-domain   |     | Inter-domain  |  |
          X   |  | Topology (IdT) |     | Resource (IdR)|  |
          X   |  +-^------^-------+     +---^-------^---+  |
          X   |    .      .                 *       *      |
          X   +----.------.-----------------*-------*------+
          X        .      .                 *       *
          X        .      .                 *       *
       +--X--------.---+*********************       *
       |               |  .                         *
       |               |  .............+------------*---+
       |     MdO1      |               |                |
       |               +<------------->+                +---+
       +---------------+               |      MdO2      |   |
                                       |                |   |
   Legend:                             +-+--------------+   |
   XXX ALTO Protocol                     |                  |
   ... BGP/BGP-LS/REST                   |      MdO(n)      |
   *** UNIFY/TOSCA/ETSI-NFV              +------------------+
```

Figure 1: Broker-assisted Multi-operator Network Architecture

5.1. Inter-domain Resource (IdR) Component

It creates a hierarchical database that contains inter-domain resource information such as resource availability (i.e., CPU, memory, and storage), Virtual Network Functions (VNFs) and Physical Network Functions (PNFs) supported and Service Access Points (SAPs) to access those resources. UNIFY [UNIFY.NFFG], TOSCA [TOSCA], ETSI-NFV [ETSI-NFV-MANO], among other data models can be used to create the interface between IdR and MdOs.

5.2. Inter-domain Topology (IdT) Component

A hierarchical TED (Traffic Engineering Database) that contains inter-domain network topology information including additional key parameters (e.g., throughput and latency of links). This information can be retrieved from each MdO through BGP-LS or REST interfaces.

5.3. ALTO Server Functionalities

The ALTO server component is the core of the broker layer. Multiple logically centralized ALTO servers use the information collected from IdR and IdT components to create and provide abstract maps with a simplified view, yet enough information about MdOs involved in the federation. This information includes domain-level topology, resource availability (i.e., CPU, memory, and storage), PNF/VNF capabilities, and SAPs.

As an ALTO client, each MdO sends ALTO service queries to the ALTO server. This server provides aggregated inter-domain information exposed as set ALTO base services defined in [RFC7285], e.g., Network Map, Cost Map and ALTO extension services, e.g., Property Map [DRAFT-PM], Multi-Cost Map [RFC8189], Path Vector [DRAFT-PV].

For example, when a source MdO receives a customer service request, it checks whether or not it can deliver the full service. If it is unable to do so, the MdO consumes from the ALTO Server the Property Map service to have a clear global view of the resource information offered by other MdOs. This information allows discovering which candidate MdOs may be contacted to deliver the remaining requirements of a requested end-to-end service deployment. The connectivity information among discovered MdOs can be retrieved by a Cost Map service, responding, for instance, a path vector with the AS-level topology distance between the source MdO and candidate MdOs.

5.4. Filtered Cost Map Extension

The ALTO server MUST provide connectivity information for every SG link in the SG path for an E2E requirement. This information is the AS-level topology distance in the form of path vector, and it includes all possible ways for each (source node, destination node) pair in the SG link.

In this section, we introduce a non-normative overview of the Filtered Cost Map defined in Section 6.1 of [DRAFT-PV] [1].

The specifications for the "Media Types", "HTTP method", "Capabilities" and "Uses" (described in Section 6.1 of [DRAFT-PV] [2]) are unchanged.

5.4.1. Accept Input Parameters

The ReqFilteredCostMap object in Section 6.1.2 of [DRAFT-PV] [3] is extended as follow:

```
object {
  NFFG sg;
} ReqFilteredCostMap;

object {
  JSONString nfs<1..*>;
  JSONString saps<1..*>;
  NextHops sg_links<1..*>;
  REQs reqs<1..*>;
} NFFG;

object {
  JSONNumber id;
  JSONString src-node;
  JSONString dst-node;
} NextHops;

object {
  JSONString id;
  JSONString src-node;
  JSONString dst-node;
  JSONNumber sg-path<1..*>;
} REQs;
```

sg: If present, the ALTO Server MUST allow the request input to include an SG with a formatted body as an NFFG object. An NFFG object contains NFs, SAPs, SG links representing logical connections between NFs, SAPs or both and E2E requirements as a list of ids of SG links.

It is worth noting that further versions of this draft will define a more elaborated NFFG object to support extended parameters such as monitoring parameters, resource requirements, etc.

5.4.2. Response

If the ALTO client includes the path vector cost mode in the "cost-type" or "multi-cost-types" field of the input parameter, the response for each SG link in each E2E requirement MUST be encoded as a JSONArray of JSONArrays of JSONStrings. Anyone of the sub-arrays indicates a potential candidate path calculated as the per-domain topological distance corresponding to the amount of traversing domains.

Moreover, as defined in Section 6.3.6 of [DRAFT-PV] [4], If an ALTO client sends a request of the media type "application/alto-costmapfilter+json" and accepts "multipart/related", the ALTO server MUST provide path vector information along with the associated Property Map information (e.g., entry points of the corresponding foreign domains), in the same body of the response.

Section 5.5.2 gives an example of the Filtered Cost Map query and the corresponding responses.

5.5. Examples of Message Exchange

This section list a couple of examples of the Property Map and Filtered Cost Map queries and the corresponding responses. These responses are based on the information in Table 1 and Table 2 of a use case implementation described in Appendix A.

5.5.1. Property Map Service

In this example, the ALTO client wants to retrieve the entire Property Map for PID entities with the "entry-point", "cpu", "mem", "storage", "port" and "nf" properties.

o HTTP Request:

```
GET /propmap/full/inet-ucmspn HTTP/1.1
Host: alto.example.com
Accept: application/alto-propmap+json,application/alto-error+json
```

o HTTP Response:


```
HTTP/1.1 200 OK
Content-Length: ###
Content-Type: application/alto-propmap+json
{
  "property-map": {
      "pid:AS1": {
          "entry-point": [ "http://172.25.0.10:8888/escape" ],
          "cpu": [ "50.0" ],
          "mem": [ "60.0" ],
          "storage": [ "70.0" ],
          "port": [ "SAP1" ],
          "nf": [ "NF1", "NF3" ]
      },
      "pid:AS2": {
          "entry-point": [ "http://172.26.0.10:8888/escape" ],
          "cpu": [ "10.0" ],
          "mem": [ "20.0" ],
          "storage": [ "30.0" ],
          "nf": [ "NF2" ]
      },
      "pid:AS3": {
          "entry-point": [ "http://172.27.0.10:8888/escape" ],
          "cpu": [ "80.0" ],
          "mem": [ "90.0" ],
          "storage": [ "100.0" ],
          "port": [ "SAP2" ],
          "nf": [ "NF1", "NF3" ]
      }
  }
}
```


5.5.2. Filtered Cost Map Service

The following example uses the Filtered Cost Map service to request the path vector for a given E2E requirement. The SG request information in Table 2 is used to describe the service, and it is composed of three NFs (NF1, NF2, and NF3) and two SAPs (SAP1 and SAP2). Links connecting the NFs and SAPs ("sg_links" tag) are also

included, followed by an E2E requirement ("reqs" tag) with information about the order in which NFs are traversed from SAP1 to SAP2.

Note that the request accepts "multipart/related" media type. This means the ALTO server will include associated property information in the same response.

o HTTP Request:

```
POST /costmap/pv HTTP/1.1
Host: alto.example.com
Accept: multipart/related, application/alto-costmap+json,
      application/alto-propmap+json, application/alto-error+json
Content-Length: [TBD]
Content-Type: application/alto-costmapfilter+json

{
  "cost-type": {
    "cost-mode": "array",
    "cost-metric": "ane-path"
  },
  "sg": {
    "nfs": [ "NF1", "NF2", "NF3" ],
    "saps": [ "SAP1", "SAP2" ],
    "sg_links":[
      {
        "id": 2,
        "src-node": "SAP1",
        "dst-node": "NF1",

      },
      {
        "id": 2,
        "src-node": "NF1",
        "dst-node": "NF2",
      },
      {
        "id": 3,
        "src-node": "NF2",
        "dst-node": "NF3",
      },
      {
        "id": 4,
        "src-node": "NF3",
        "dst-node": "SAP2",
      }
```

```
        ],
        "reqs": [
          {
            "id": 1,
            "src-node": "SAP1",
            "dst-node": "SAP2",
            "sg-path": [ 1, 2, 3, 4 ]
          }
        ]
      }
    }
```


- o HTTP Response: The ALTO server returns connectivity information for the E2E requirement provided by the ALTO Client request of the above example.

  For each SG link in the E2E requirement (SAP1->NF1, NF1->NF2, NF2->NF3, NF3->SAP2), the ALTO server returns sub-arrays indicating potential candidate paths calculated as the AS-level topological distance corresponding to the amount of traversing domains.

  Also, the response includes Property Map information for each element in the path vector. In this case, it is retrieved a Property Map with the "entry-point" property, i.e., the URL of the MdO entry point for the corresponding network.


```
HTTP/1.1 200 OK
Content-Length: [TBD]
Content-Type: multipart/related; boundary=example

--example
Content-Type: application/alto-endpointcost+json

{
  "meta": {
    "cost-type": {
       "cost-mode": "array",
       "cost-metric": "ane-path"
     },
  },

  "cost-map": {
    "SAP1": {
      "SAP2": {
```

```
               "SAP1": {
                   "NF1": [
                     [ "AS1" ], [ "AS1", "AS2", "AS3" ]
                   ]
               },
               "NF1": {
                   "NF2": [
                     [ "AS1", "AS2" ], [ "AS3", "AS2" ]
                   ]
               },
               "NF2": {
                   "NF3": [
                     [ "AS2", "AS1" ], [ "AS2", "AS3" ]
                   ]
               },
               "NF3": {
                   "SAP2": [
                     [ "AS1", "AS2", "AS3" ], [ "AS3" ]
                   ]
               }
           }
         }
       }
     }

     --example
     Content-Type: application/alto-propmap+json

     {
       "property-map": {
         "pid:AS1": { "entry-point": "http://172.25.0.10:8888/escape" },
         "pid:AS2": { "entry-point": "http://172.26.0.10:8888/escape" },
         "pid:AS3": { "entry-point": "http://172.27.0.10:8888/escape" }
       }
     }

     --example--
```

6. Discussion

In this section, we analyze the benefits and open issues in our broker-assisted architecture.

6.1. Benefits

The broker-assisted orchestration has numerous benefits, such as:

- o Avoid the distribution of topology and resource information in a peer-to-peer fashion (MdO-to-MdO)
- o The (abstracted) information and offered resources, services are maintained in each local MdO.
- o Allow domains without physical infrastructure (hence without BGP or BGP-LS) to advertise their capabilities.
- o An ALTO-based privacy-preserving information model to provide computing, storage, and networking resource info.
- o An MdO discovery method to determine the underlying network graph and a potential set of paths before bilateral negotiation between MdOs is started.

6.2. Open Issues

Although the broker-assisted information exchange has several advantages, it also raises some questions which we try to answer from our lessons learned.

- o What kind of organization will manage and support the operation of a broker entity? If a broker is used to exchange information, then how does one ensure that the data delivered amongst the operators by this 3rd party has not been changed?
  - * The broker entity must be trusted by each operator since it stores and handles sensitive information. For example, future deployment of SDN at IXPs can be used as a trusted third-party platform to support rich business models between different operators [DRAFT-HHSFC].
- o In the case of peer-to-peer information exchange model, an MdO failure concerns only the domain where the failure occurs, other peers can perform the information exchange without any limitation. However, If any error occurs in the broker entity the information exchange among all involved ASes will be impacted. How avoid this single point of failure?
  - * The broker entity maintains a centralized database. Local restoration/replication options may be applied.

o The MdO information exchange depends on the policies. Operators have a preference to share a different view about its compute and network resources towards different operators. For example, a detailed view for the operators that are belonging to same operator group and a high-level information towards the other operators. How is the fine-grained/coarse-grained information exchange handled?.

  * It requires much more complex database handling and information exchange with the MdOs depending on the policies.

7. IANA Considerations

This document includes no request to IANA.

8. Security Considerations

TBD.

9. Acknowledgments

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Appendix A. Proof of Concept Use Case Implementation

A strawman use case scenario has been implemented following the architectural proposal of the 5GEx project [H2020.5GEX]. It refers to an E2ENS orchestration involving three administrative domains. For reproducibility purposes, all supporting codes are publicly available in our research group repository: https://intrig.dca.fee.unicamp.br:8865/intrig-unicamp/alto-based-broker-assisted-mdo

As shown in Figure 2, each administrative domain has an MdO (MdO-AS1, MdO-AS2, and MdO-AS3) to coordinate resource and/or service orchestration at multi-operator level via interface I2 APIs. For the orchestration within the same administrative domain, each MdO uses emulated DOs with emulated I3 interfaces, since no data-plane is present. DOs use static configuration files to load local information about resources (I3-RC) and topology (I3-RT). The different MdO components are based on existing open source tools such as ESCAPE [H2020.5GEX.ESCAPE] (Service/Resource Orchestrator) and Netphony-topology [TELEFONICA.NET.TOPO] (Resource Topology) and run in Docker containers on a single computer. Besides, MdOs expose I1 interfaces to the tenants who request services and/or slices which should follow a Network Function Forwarding Graph (NFFG) [UNIFY.NFFG] format.

In case of the broker layer, the IdR and IdT components use a UNIFY Virtualizer API [UNIFY.NFFG] (broker-based I2-RC API) and a REST API (broker-based I2-RT API) respectively, in order to create the hierarchical databases. Regarding the IdT, the administrative domain 2 is a transit provider so that the domain-level topology computed is: AS1-AS2-AS3. From the inter-domain information are created the two different ALTO Map Services: (i) Property Map and (ii) Cost Map.

```
                            +----------------------------------------+
                            |       +---------------+    BROKER LAYER|
                       XXXXXXXXXXXXXX  ALTO Server  |                |
                       X    |       +--------+----+-+                |
                       X    |               /      \                 |
                       X    | +-----------+/+--+  +-\-------------+  |
                       X    | | Inter-domain   |  | Inter-domain  |  |
       +-----------+   X    | | Topology (IdT) |  | Resource (IdR)|  |
       | Service   |   X    | +----------------+  +---------------+  |
       | Graph (SG)|   X    +---------^-^----------------^--^--------+
       | Request   |   X              * *    .............  .
       +-----+-----+   X              * *    . ..............
             |         X              * *    . .              MdO-AS3
           I1|         X              * *    . .      +--------------+
             |         X     MdO-AS1  * *    . .      |              |
       +-----|---------X-----------+  * *    . .      |     MdO-AS2  |
       |     |                     |  * *    . .   +---------------+ |
       | +---v-------------------+ |  * *    . .   | +-----------+ | |
       | |                       | |  * *    . .   | |           | | |
       | |  Network Service Orch.| |  * *    . .   | |   NSO     | | |
       | |  (NSO)                | |  * *    . .   | |           | | |
       | +-----------------------+ |  * *    . .   | +-----------+ | |
       |                           |  * *    . .   |               | |
       | +---------+               |  * *    . .   | +---+         | |
       | | Resource........................... .   | |   |         | |
       | | Topoloy |               |  * *      .......RT |         | |
       | | (RT)    | +-----------+ |  * *          | |   |         | |
       | +---------+ |Resource   | |  * *          | +---+   +---+ | |
       |             |Orch.      | |  * **********************   | | |
       |             |(RO)       ******            |         |RO | +-+
       |             +-----------+ |               |         |   | |
       |                           |<------------->|         +---+ |
       +---------------------------+      I2       +-----+---------+
                  /     \                                |
               I3/       \                               |I3
       +-------+---+  +-----------+                +-----------+
       | Domain    |  | Domain    |                | Domain    |
       | Orch (DO) |  | Orch (DO) |                | Orch (DO) |
       +-----------+  +-----------+                +-----------+
                                            Legend:
                                            XXX ALTO Protocol
                                            ... broker-based I2-RT API
                                            *** broker-based I2-RC API
```

Figure 2: Broker-assisted 5GEx Info Exchange

The Property Map includes property values grouped by Autonomous System (AS). Such values are SAPs, NFs and the 5GEx Entry Point (e.g., the URL of the ESCAPE orchestrator). An example of the Property Map in our prototype is:

	Entry Point	Port SAP	Capabilities	CPU	MEM	Storage	...
AS1	http://...	SAP1	{NF1, NF3}	50	60	70	...
AS2	http://...	-	{NF2}	10	20	30	...
AS3	http://...	SAP2	{NF1, NF3}	80	90	100	...

Table 1: ALTO Property Map

The Cost Map defines a path vector as an array of ASes, representing the AS-level topological distance for a given E2ENS request. Path vector constraints (as described in the Multi-Cost Map [RFC8189]) can be applied to restricts the response to costs that satisfy a list of simple predicates.

Table 2 below shows a brief example of an SG request and its path vector response containing a list of potential providers to be traversed to deliver such service. Every AS path is computed from the inter-domain topology information in the IdT module. In our scenario, MdO-AS2 is a transit provider, so that the domain-level topology map is AS1<->AS2<->AS3.

Service Graph (SG) Request	Path(s) Vector
SAP1->NF1->NF2->NF3->SAP2	1:{AS1:SAP1->AS1:NF1->AS2:NF2->AS3:NF3->AS3:SAP2} 2:{AS1:SAP1->AS1:NF1->AS2:NF2->AS1:NF3->AS2->AS3:SAP2} 3:{AS1:SAP1->AS2->AS3:NF1->AS2:NF2->AS3:NF3-AS3:SAP2} 4:{AS1:SAP1->AS2->AS3:NF1->AS2:NF2->AS1:NF3->AS2->AS3:SAP2}

Table 2: ALTO Cost Map

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