Paper

Application of open multi-commodity market data model on the communication bandwidth market

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Abstract— In the paper the market model for balancing communication bandwidth trade (BCBT) is analyzed in the form of multi-commodity market data model (M^3). The distinguishing feature of BCBT model is that it assumes that market players can place buy offers not only for isolated network resources – inter-node links, but also for end-to-end network paths of predefined capacity, that is, every offer concerns a point-to-point bandwidth connection between a pair of specified locations in a communication network. The model enables effective balancing of sell and buy offers for network resources in a way which maximizes global economic welfare. The open multi-commodity market data model provides efficient and clear mechanisms, which support the environment of auctions and multi-commodity exchanges, especially when the trade is constrained by the infrastructure resources. Thus the model may be used in designing open information systems for market balancing and clearing in the context of multi-commodity trade in various network infrastructure sectors.

Keywords— communication bandwidth trade, market clearing, multi-commodity trade.

1. Introduction

Communication bandwidth trading is typically accomplished by bilateral agreements between telecom companies. The agreements are usually settled using complex and nontransparent negotiations, which cause the whole process difficult to automate. Still increasing number of traders and complexity of network resources and services also have big impact on difficulties in elaborating complex information system serving exchange processes. Thus, the need for fair, efficient and clear market rules, in the form of, e.g., auctions, markets or exchange, becomes quite evident.

The primary requirement of the multi-commodity market data model (M^3) is an easy exchange of all data between various market entities and market balancing processes. The M^3 model consists of several layers, which are the formal mathematical model (see [7]), conceptual data model, expressed in form of UML class diagrams (see [6, 7, 11]), exemplary relational database structure, XML schemas for static data (see [11]), communication models, XML schemas for messages, and Web services definitions.

Main purpose of the paper is to present the application of M^3 for the balancing communication bandwidth trade (BCBT) problem and to demonstrate that M^3 is a suitable tool for designing the communication bandwidth markets. We analyze the case study from [14]. In the example, data exchange process is presented, including offer submission, status of the auction broadcasting, resending statuses of particular offers, etc. The snippets of XML files, containing pieces of static data, are presented.

2. Data model standard for multi-commodity markets

At present, in many network industries, functionality and efficiency of the existing control and management designs are not completely satisfactory. The world-wide market liberalization and deregulation processes are being implemented in many network infrastructure sectors, including telecommunication, power systems, computer, rail and transport networks, water, urban systems and others.

Many researchers and professionals around the world participate in development, investigation and implementation of a variety of new ideas related to auction and market clearing systems under various market conditions. In the network systems, an efficient market balance may be obtained in a single balancing process by joint optimization of trade of many elementary commodities and services related to buy and sell offers of the network resources. For this purpose the multi-commodity exchanges can be used, in addition to single-commodity exchanges and bilateral trading. The basic multi-commodity market clearing models are in the LP or MILP forms (see [15]).

Apart from traditional auctions, long-term and medium-term single-commodity market segments, or day-ahead and intra-day-markets, there is a need for designing specific problem-oriented multi-commodity auctions and balancing market mechanisms, which must provide feasible execution of sales contracts and assure timely delivery of many goods and services.

In our previous research [11] we have initiated the design of the open multi-commodity market data model that may be used in designing information systems for market balancing and clearing in the context of multi-commodity trade in various network infrastructure sectors. In this paper we address the generic telecommunication design issues of M^3. One purpose of the open M^3 model is that it creates a flexible framework for development of new market models and algorithms, benchmark data repository, and gives possibility for integration of software components which implement balancing mechanisms. Finally, it will help the community to determine the best industrial standards of data interchange and enable for an easy public access and exchange of various market data.

3. M^3 and the BCBT market

In Fig. 1, we can see four nodes (A, B, C and D), five inter node links (solid lines), which are simultaneously the sell offers and two buy offers, concerning end-to-end network paths (dashed lines). Sell offer notation: "x/y" means willingness to sell up to y units of bandwidth at price at least x. Buy offer notation: "$d : x/y$" means that buyer d has willingness to buy up to y units of bandwidth at price x or lower.

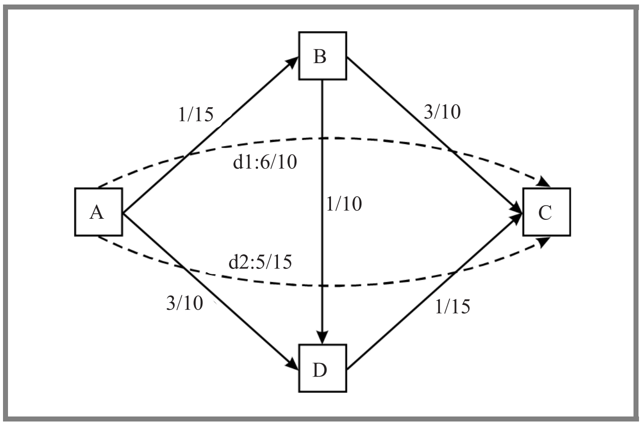

Fig. 1. Physical telecommunication network.

3.1. Infrastructure

To set a correct infrastructure model, we need to define physical network (Fig. 1). On the BCBT market commodities and offers are defined in context of network, so the description of network is in the core of M^3 data model. Network is modeled as acyclic graph, for the sake of generality let us assume N graphs, where nth graph is defined by $\langle V^n, E^n, P^{V^n}, P^{E^n} \rangle$, $n \in N$ is an index of network model, V^n is a set of nodes, E^n is a set of edges, P^{V^n} and P^{E^n} are parameters of vertices and arcs, respectively.

In M^3 model the commodities which are in our example, i.e., physical links and end-to-end network paths, have to be associated to one of network nodes, or edges. As the end-to-end network path should be associated to the network edge, but the edge could not exist (e.g., there is not edge for path A-C, see Fig. 1). The M^3 model allows for defining a virtual networks, which are an aggregation of a lower level network. Thus the need to define network with all connection between every pair of nodes, that is the complete network (Fig. 2), is obvious.

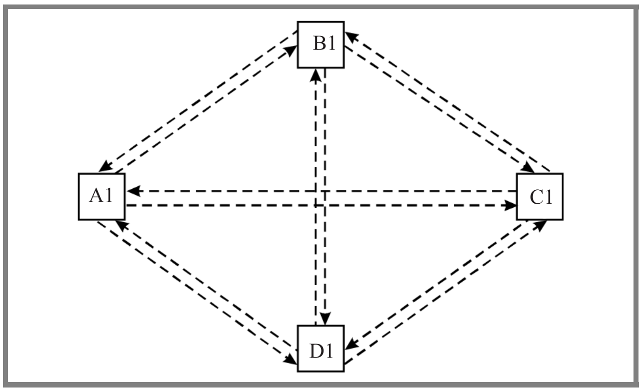

Fig. 2. Complete, virtual network.

Every graph consists of set of edges and nodes. Definition of a single node in one of the networks is the following (node A):

```
<m3:node id="ex:nodeA"
  dref="ex:CommunicationNode">
 <m3:name>Node A</m3:name>
</m3:node>
```

The `dref="ex:CommunicationNode"` attribute means that this node is an instance of a `CommunicationNode` which is a `NetworkNodeKind` and is defined as

```
<m3:NetworkNodeKind
   id="ex:CommunicationNode">
  <m3:name>Node</m3:name>
  <m3:description>
    Definition of node in communication
    network
  </m3:description>
</m3:NetworkNodeKind>
```

The `CommunicationNode` is a simple meta-class. It contains only required set of elements and attributes, like unique *identifier*, *name* of the class and the human readable *description* of the class.

Definition of a particular arc, for example arc A-B, is the following:

```
<m3:arc id="ex:arcA-B"
   dref="ex:BandwidthPath">
  <m3:parameter
    dref="ex:Capacity">15</m3:parameter>
  <m3:predecessor ref="ex:node1"/>
  <m3:successor ref="ex:node2"/>
</m3:arc>
```

The m3:predecessor element references to a predecessor of this arc, similarly the m3:successor element references to a successor of this arc. The dref="ex:BandwidthPath" attribute means that this arc is an instance of a BandwidthPath which is defined:

```
<m3:NetworkArcKind id="ex:BandwidthPath">
  <m3:name>Physical link</m3:name>
  <m3:description>
    Definition of link in
    a physical communication network
  </m3:description>
  <m3:ParameterDefinition id="ex:Capacity"
    dataType="xsd:double" required="true"
    unitOfMeasure="Tb/month">
    <m3:name>Capacity of the link</m3:name>
  </m3:ParameterDefinition>
</m3:NetworkArcKind>
```

In addition to required elements, this meta-class contains a parameter element m3:parameter. It references to parameter definition dref="ex:Capacity", which contains short *name* of the parameter, human-readable *description* of it, *data type*, attribute which defines if the generic parameter is *required* in all instances and the optional *unit of measure*. Thanks to parameter elements, we can model complex components like, e.g., network links, generating units, etc.

3.2. Time structure

Each balancing process is related to a time structure. Commodities are to be delivered in determined time slots. Thus the time horizon must be divided into time segments and every commodity is related to the specific time slot. The time structure is modeled as a directed acyclic graph $C = \langle V^C, E^C \rangle$, where vertices V^C define time slots, and edges describe aggregation between time slots. Time structure includes basic time slots, e.g., hours. By aggregations of time slots one may form more sophisticated slots, e.g., load peak hours or days of week.
The time structure for the BCBT is very simple – it contains time periods which are particular months:

```
<m3:calendar>
 <!-- ... -->
 <m3:CalendarPeriod id="ex:M0704"
   periodType="ex:one-month"
   startTime="2007-04-01T00:00:00"
   endTime="2007-05-01T00:00:00"/>
 <m3:CalendarPeriod id="ex:M0705"
   periodType="ex:one-month"
   startTime="2007-05-01T00:00:00"
   endTime="2007-06-01T00:00:00"/>
 <m3:CalendarPeriod id="ex:M0706"
   periodType="ex:one-month"
   startTime="2007-06-01T00:00:00"
   endTime="2007-07-01T00:00:00"/>
 <!-- ... -->
</m3:calendar>
```

Nevertheless the time structure could have more complex structure in case of commodities defined for different time slots simultaneously, e.g., days and months.

3.3. Market entities

Market entities structure describes market players and relations between them. Again, it is modeled as a directed acyclic graph. Market entities form a hierarchy, where a given market entity may be composed of some other market entities. Market entities are related to infrastructure vertices. This relation has different semantic, depending on relation type, e.g., is located, can deliver commodities, etc.:

```
<!-- buyer -->
<m3:MarketEntity id="ex:buyer-d1"
  dref="m3:bandwidth-buyer">
  <m3:name>buyer-d1</m3:name>
  <m3:uri>
    http://www.bandwidth.buyer.pl/d1
  </m3:uri>
</m3:MarketEntity>
<!-- remaining buyers ... -->
<!-- seller -->
<m3:MarketEntity id="ex:brokerA-B"
  dref="m3:link-broker">
  <m3:name>brokerA-B</m3:name>
  <m3:uri>
    http://www.link.broker.pl/A-B
  </m3:uri>
</m3:MarketEntity>
<!-- remaining sellers ... -->
```

3.4. Commodities

In M^3 the commodity have to be associated to some node or edge from infrastructure model. Such association can have different meanings, e.g., some commodity could be put on the market in particular network node. The commodity have to be also related to some time slot from time structure. Finally, the definition of commodity kind has to be included. In our example we have two kinds of commodities, i.e., physical links and end-to-end network paths. Because we have five edges in physical network, we could define up to five different commodities of kind physical link in single time slot (with assumption, that physical link commodity could be associated only to edge of base network). Similarly, as we have twelve different edges in the complete network, we can define up to twelve different commodities of kind network path in single time slot (with assumption, that network paths commodity could be associated only to edge of complete, virtual network):

```
<!-- one of links -->
<m3:Commodity id="ex:btH0705-D-C"
  dref="ex:bandwidth-trade-link">
  <m3:description>
    Bandwidth trade link D-C on May 2007
  </m3:description>
  <m3:availableAt ref="ex:arcD-C"/>
  <m3:CalendarScheduledCommodity
    ref="ex:M0705"/>
</m3:Commodity>
<!-- path -->
<m3:Commodity id="ex:vpA1-C1M0705"
    dref="ex:bandwidth-trade-path">
  <m3:description>
    Bandwidth end-to-end network path
    A1-C1 on May 2007
  </m3:description>
  <m3:availableAt ref="ex:arcA1-C1"/>
  <m3:CalendarScheduledCommodity
    ref="ex:M0705"/>
</m3:Commodity>
```

3.5. Offers

Data model M^3 provides three types of offers: simple, integrated and grouping offers. Simple offer is described by admissible range of commodity volumes and a unit price. Integrated offer is a typical type of offer for multi-commodity turnover, where players trade with packages (or bundles) of commodities with fixed proportions of commodities in the offer. The most complex type of offers are grouping offers. Grouping offers aggregate a subset of other simple or integrated offers and describes relation between these offers. Grouping offers allow the market entities to define individual constraints.
The input offers are the elementary offers:

```
<!-- sell offer -->
<m3:Offer id="ex:o20421-89"
    offeredPrice="1.00">
  <m3:description>
    Bandwidth sell offer on the edge A-B
  </m3:description>
  <m3:offeredBy ref="ex:brokerA-B"/>
  <m3:offerStatus status="m3:offer-open">
    <m3:durationPeriod startTime="2007-05"
      endTime="2007-06"/>
  </m3:offerStatus>
  <m3:volumeRange minValue="0"
    maxValue="15"/>
  <m3:ElementaryOffer>
    <m3:offeredCommodity shareFactor="1"
      ref="ex:btH0705-A-B"/>
  </m3:ElementaryOffer>
</m3:Offer>
<!-- buy offer -->
<m3:Offer id="ex:o20421-94"
   offeredPrice="6.00">
  <m3:description>
    Point-to-point bandwidth buy offer,
    from point A to C
  </m3:description>
  <m3:offeredBy ref="ex:buyer-d1"/>
  <m3:volumeRange minValue="0"
    maxValue="10"/>
  <m3:ElementaryOffer>
    <m3:offeredCommodity shareFactor="-1"
      ref="ex:vpA1-C1M0705"/>
  </m3:ElementaryOffer>
</m3:Offer>
```

To provide properly defined output flows in the network, a detailed flow must be provided for each end-to-end buy offer, so the output offers are represented as the bundled offers, where each elementary offer represents flow on particular arc. Let us focus on the d1 buy offer, and assume

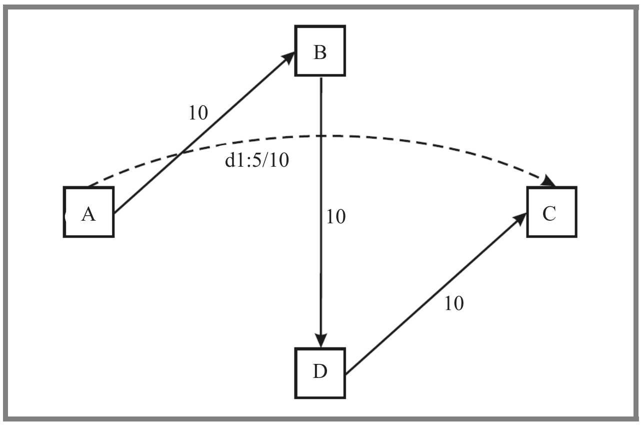

Fig. 3. Output offer for buyer d1.

that it is accepted with volume 10, on the path A-B-D-C (Fig. 3). The output offer is as follows:

```
<!-- output buy offer -->
<m3:Offer id="ex:o20421-94"
    offeredPrice="6.00"
    buyPrice="5.0" acceptedVolume="10">
  <m3:description>
    End-to-end bandwidth buy offer
    from point A to C
  </m3:description>
  <m3:offeredBy ref="ex:buyer-d1"/>
  <m3:volumeRange minValue="0"
    maxValue="10"/>
  <m3:BundledOffer>
    <m3:offeredCommodity shareFactor="1"
      ref="ex:A-BM0705"/>
    <m3:offeredCommodity shareFactor="1"
      ref="ex:B-DM0705"/>
    <m3:offeredCommodity shareFactor="1"
      ref="ex:D-CM0705"/>
  </m3:BundledOffer>
</m3:Offer>
```

4. Summary

Present trade can be greatly improved by introducing multi-commodity turnover rules. M^3 is not limited to telecommunication markets, it may be used on other infrastructure markets, for example on energy and transmission rights market, many different commodities/services can exist, e.g., energy, flowgate rights, point-to-point optional transmission rights, point-to-point obligatory transmission rights, put and call options for energy, and various reserves. As the specified commodities are strictly tied, there is no possibility to form seven different markets. Elaborated mechanisms of multi-commodity trade are sufficient also to design others markets. Designed and planned applications of M^3 exists, e.g., different energy turnover platforms, power balancing markets, multi-stage markets [7], etc. In context of the distributed environment of multilateral, multi-commodity turnover, this paper forms a basis for future work on a M^3 model. Further work is to evolve syntax of simple object access protocol (SOAP) messages, elaborate other classes of offers.

The paper presents the overall design of the open multi-commodity market data model. The proposed model has many potential practical applications. As it was shown, M^3 may be used in a wide range of market-oriented network systems and may significantly facilitate communication, coordination and modeling procedures. Especially the classes of balancing processes for which M^3 adequately describes required data include multi-stage markets – where the whole market balance is obtained as a result of number of consecutive balancing processes, multilateral distributed multi-agent market systems – where clearing is performed in distributed environment of different points of service. M^3 may be used in designing information systems for market balancing and clearing in the context of multi-commodity trade in various network infrastructure sectors. M^3 provides a set of formal data models, which results in XML-derived information interchange specification. The unified data model may enable cooperation and easy data exchange between different research teams, as well as the market entities.

Acknowledgments

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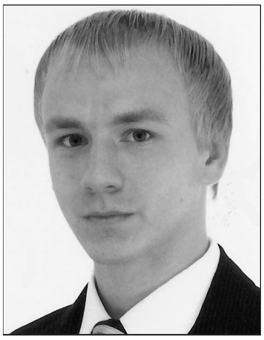

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