A Reference Model for Managing Large-Scale Software-Defined Network (SDN) Infrastructures

Klaus Wehmuth and Artur Ziviani

National Laboratory for Scientific Computing (LNCC), Brazil
SDNs getting complex

- Possibly multiple/hierarchical/distributed controllers
- Complex data planes
- Complex relations between applications
  - e.g. management applications based on info gathered from other applications
SDNs are Multi-layered

• From its basic definition: SDNs have Application, Control, and Data layers

• A multi-layered system can be extended to absorb the increasing complexity in the SDN landscape

• Each of these layers may be sub-divided into sub-layers (e.g. hierarchical controllers)

• Additional layers may be added in specific deployments (e.g. a layer for NFVs)
Representation of Multi-layer Networks
MultiAspect Graphs (MAGs)

- MAGs can represent **Multi-layer Time-varying** networks, or even more complex objects
- Edges are even tuples, $e = (a_1, \ldots, a_n, b_1, \ldots, b_n)$
- MAGs are proven to be equivalent to directed graphs
- MAG algebraic representations and algorithms can be derived from well-known directed graph representations and algorithms

- **On MultiAspect Graphs**, *Theoretical Computer Science, 651, pp. 50-61, Oct 2016*
  K. Wehmuth, E. Fleury, A. Ziviani, pre-print available at arXiv 1408.0943

- **MultiAspect Graphs: algebraic representation and algorithms**, 
  K. Wehmuth, E. Fleury, A. Ziviani, pre-print available at arXiv 1504.07893
Multilayer Graph (MLG)

MLG is a particular case of MAG

\[ G = (V, E, L) \]

- \( V \) - Vertex set
- \( E \) - Edge set
- \( L \) - Layer set
Edges

\[ E \subseteq V \times L \times V \times L \quad \text{e} \in E, \text{ e } = (v_1, L_a, v_2, L_b) \]

\[ v_1, v_2 \in V \text{ - Vertices} \]

\[ L_a, L_b \in L \text{ - Layers} \]

An edge expresses a relation between two vertices at two layers
Edges

\[ E \subseteq V \times L \times V \times L \]

\[ e \in E, \ e = (v_1, L_a, v_2, L_b) \]

\[ v_1, v_2 \in V - \text{Vertices} \]

\[ L_a, L_b \in L - \text{Layers} \]

An edge expresses a relation between two vertices at two layers.
Edges Types

Inter-layer Edges
Intra-layer Edges
Mixed Edges

L₀

L₁

(0, L₀₁₀₁)
(2, L₀₁₁₁)
(1, L₁₂₁₁)
(2, L₁₁₁₁)
Composite Vertices

\[ G = (V, E, L) \]

\[ V = \{0, 1\} \]
\[ L = \{L_0, L_1, L_2\} \]

\[ e = (v_1, L_a, v_2, L_b) \]

\[ u, v \in V_s = V \times L \]
Composite Vertices Representation

\[ G = (V, E, L) \]

\[ V = \{0, 1\} \]

\[ L = \{L_0, L_1, L_2\} \]

\[ e = (v_1, L_a, v_2, L_b) \]

\[ u, v \in V_s = V \times L \]

\[
\begin{array}{c}
(0, L_0) \quad (0, L_0, 0, L_1) \\
(0, L_1) \quad (0, L_1, 1, L_2) \\
(1, L_0) \quad (0, L_1, 1, L_1) \\
(1, L_1) \quad (1, L_1, 0, L_2) \\
(1, L_2) \quad (1, L_0, 1, L_1)
\end{array}
\]
MLG Example
MLG Paths

Paths are established by antecessor/successor relations
MLG shortest paths
Adjacency Matrix
A reference model for SDNs based on MLGs
SDN Example

A1 \(\rightarrow\) C \(\rightarrow\) D1
A2 \(\rightarrow\) C \(\rightarrow\) D2
A3 \(\rightarrow\) C \(\rightarrow\) D3

C \(\rightarrow\) D4
D2 \(\rightarrow\) D5
D3 \(\rightarrow\) D4

Application layer
Control layer
Data layer
Take Away Messages

A reference model for SDNs based on MLGs

• Can represent SDNs with arbitrary number of layers
• Is equivalent to a directed graph
• Can be represented by matrices or any other form of direct graph representation
• Can use well-known graph algorithms for the analysis of the SDN structure
  • e.g. controller location, management of distributed controllers, study of intra- and inter-layers flows, …
Thanks!

Klaus Wehmuth & Artur Ziviani
(LNCC)
{klaus,ziviani}@lncc.br

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