Contention Management for 5G

DB,CC,MG,OM,YS

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Abstract

This article treats about Contention Management for 5G.

1 Introduction

- Context and problematic
- Related works
- Article contribution

2 Model, Problems

2.1 Definitions

We consider a symmetric directed graph $G = (V, A)$ modelling a network. Each arc (u, v) in A is labeled by an integer $Dl(u, v) \geq 1$ that we call the delay and which represents the number of time slots taken by a signal to go from u to v using this arc. Note that for any arc (u, v), $Dl(u, v) = Dl(v, u)$.

A **route** r in G is a sequence of consecutive arcs $a_0, \ldots, a_{k-1}$, with $a_i = (u_i, u_{i+1}) \in A$.

The **latency** of a vertex u_i in r, with $i \geq 1$, is defined by

$$\lambda(u_i, r) = \sum_{0 \leq j < i} Dl(a_j)$$

We also define $\lambda(u_0, r) = 0$. The latency of the route r is defined by $\lambda(r) = \lambda(u_k, r)$.

A **routing function** $\mathcal{R}$ in G associates to each pair of vertices (u, v) a route from u to v. Let $\mathcal{C}$ be an **assignment** in G, i.e., a set of couples of different vertices of G. We denote by $\mathcal{R}_{\mathcal{C}}$ the set of routes $\mathcal{R}(u, v)$ for any (u, v) in $\mathcal{C}$. TODO: Est-ce qu'on doit ajouter que le routage est cohérent ?

2.2 Slotted time Model

Consider now a positive integer P called the **period**. A **P-periodic affectation** of $\mathcal{R}_{\mathcal{C}}$ consists in a set $\mathcal{M} = (m_0, \ldots, m_{c-1})$ of c integers that we call **offsets**, with c the cardinal of $\mathcal{C}$. In our problem the messages we send in the network will be periodic of period P and thus we consider slices of time of P slots. The number m_i represents the number of the first slot used by the route $r_i \in \mathcal{R}_{\mathcal{C}}$ at its source in a period. We define the first time slot at which a message reaches any vertex v in this route by

$$t(v, r_i) = m_i + \lambda(v, r_i) \mod P.$$

A message usually cannot be transported in a single time slot. We denote by τ the number of slots necessary to transmit a message. Let us call $[t(v, r_i)]$ the index of the time slots used by a route r_i at a vertex v in a period P. Those values are forming a consecutive set of values starting at $t(v, r_i)$ and ending at $t(v, r_i) + \tau \mod P$. A P-periodic affectation must have no **collision** between two routes in $\mathcal{R}_{\mathcal{C}}$, that is $\forall (r_i, r_j) \in \mathcal{R}_{\mathcal{C}}^2, i \neq j$, we have

$$[t(u, r_i)] \cap [t(u, r_j)] = \emptyset.$$

2.3 Problems

TODO: Mettre une phrase ou deux pour faire le lien avec le problème concret, plus facile faire une fois l'intro écrite The main theoretical problem we have to deal with in this context is the following.

Problem Periodic Routes Assignment (PRA)

Input: a graph $G = (V, A)$, a set $\mathcal{C}$ of pair of vertices, a routing function $\mathcal{R}$ and an integer P.

Question: does there exist a P-periodic affectation of $\mathcal{C}$ in $(G, \mathcal{R})$?

We deal in next section with the complexity of the Problem PRA.

In the context of cloud-RAN applications, we consider here the digraph $G = (V, A)$ modeling the target network and two disjoint subsets of vertices S and L, where S is the set of BBU and L is the set of RRH. We denote by n the size of S and L. We are given a period P, a routing function $\mathcal{R}$ and a bijection $\rho : L \to S$ which defines two disjoint assignments $\mathcal{C}_1 = \{(l, \rho(l))\}_{l \in L}$ and $\mathcal{C}_2 = \{(s, \rho^{-1}(s))\}_{s \in S}$. Let $\mathcal{M} = (m_1, \ldots, m_n)$ and $\mathcal{W} = (w_1, \ldots, w_n)$ be two P-periodic affectations, of respectively $\mathcal{R}_{\mathcal{C}_1}$ and $\mathcal{R}_{\mathcal{C}_2}$.

The process realized periodically (i.e. initiated in each window of size P) for each leaf $l \in L$ is the following one (see Figure **??**). First, a message of τ slots is sent from l to $\rho(l)$ on $\mathcal{R}(l, \rho(l))$ at slot m_l in the current window. After receiving this message, $\rho(l)$ computes it during a time equal to θ slots.TODO: Je suis contre le theta dans le modèle, car il ne set à rien. On peut dire par contre dans le blabla autour du modèle qu'on simule le temps de calcul par des arêtes plus longues

Then, a message of τ slots containing the computed result is sent back from $\rho(l)$ to l on $\mathcal{R}(\rho(l), l)$, after waiting for w_l slots. Thus, the whole proccess time for l is equal to

$$PT(l) = \lambda(\mathcal{R}(l, \rho(l))) + \theta + w_l + \lambda(\mathcal{R}(\rho(l), l)).$$

TODO: Il manque le fait qu'il n'y a pas de collisions ni à l'aller ni au retour. The **maximum process time** of $(\mathcal{M}, \mathcal{W})$ is defined by $MT((\mathcal{M}, \mathcal{W})) = \max_{l \in L} PT(l)$. The problem we want to solve, is the following.

Problem Periodic Assignment for Low Latency(PALL)

Input: a digraph G, a matching ρ of a set S into a set L in G, a routing function $\mathcal{R}$, a period P, an integer T_{max}.

Question: does there exist a pair of $(\mathcal{M}, \mathcal{W})$ P-periodic affectation $\mathcal{M}$ of $\mathcal{C}_\rho$ in $(G, \mathcal{R})$ such that $MT(\mathcal{M}) \leq T_{max}$?

3 PRA Solving

3.1 NP-Hardness

TODO: Definition of the load. La preuve se réfère à la précédente qui n'a pas été retenue, il faut du coup tout expliquer.

Theorem 1. *Problem PRA cannot be approximated within a factor $n^{1-o(1)}$ unless $\mathsf{P} = \mathsf{NP}$ even when the load is two and n is the number of pairs in the assignment.*

Proof. We reduce PRA to graph coloring. Let G be a graph instance of the k-coloring problem. We define H in the following way: for each vertex v in G, there is a route r_v in H. Two routes r_v and r_u share an edge if and only if (u, v) is an edge in G and this edge is only in this two routes. We put a weight inbetween shared edges in a route so that there is a delay k between two such edges.

As in the previous proof, a k-coloring of G gives a k-periodic schedule of H and conversly. Therefore if we can approximate the value of PRA within a factor f, we could approximate the minimal number of colors needed to color a graph within a fator f, by doing the previous reduction for all possible k. The proof follows from the hardness of approximability of finding a minimal coloring [**?**]. □

3.2 MIN-PRA

Exemple de cas simple

4 Proposed Solutions, solving PALL

In this section, we consider a particular case of the model, in which for each (u, v) , the route is the same in both directions. This means that $\mathcal{R}(u, v)$ uses the same arcs as $\mathcal{R}(v, u)$ in the opposite orientation.

4.1 Intro

PALL NP-Hard car PRA NP-Hard
Résultats valables sur Topologie 1 avec nos paramètres TODO: J'ai viré star affectation, car je pense qu'il n'y a rien à dire là dessus.

4.2 No waiting times

4.2.1 Shortest-longest

Algo

Period

4.2.2 Exhaustive generation

Décrire l'algo, expliquer les coupes

4.2.3 Results

Resultats des simulations : Shortest-longest optimal pour ces parametres.

4.3 Allowing waiting times

4.3.1 Intro

Importance des waiting times quand la période est donnée (Résultats D'éxepriences et preuve avec l'exemple)

4.3.2 LSG

Algorithm

Analysis Parler de LSO et expliquer pourquoi LSG mieux avec nos params

4.3.3 Results

Random

Distributions

5 Conclusion