Real-time Management of Queue Spillovers along an Arterial

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INTRODUCTION

When demand exceeds the capacity at the signalized intersections along arterials, queues fail to clear during the allocated green times. This leads to excessive queues and when they reach the upstream intersection a queue spillback occurs. This results in a significant reduction of the intersection's capacity both for the through traffic and the cross-street traffic entering the arterial, thus leading to excessive delays.

Identification of queue spillovers has already been addressed in the past with loop detector data (Geroliminis and Skabardonis, 2011). Recently, identification and control of spillbacks has been proposed based on connected vehicle technology (Christofa et al., 2012). However, most of the state-of-practice arterial control strategies do not handle the occurrence of spillovers or treat them only locally (e.g. the SCOOT system). In this paper, we aim at developing a global arterial signal control strategy in order to mitigate impacts of queue spillovers. The proposed arterial traffic management system consists in two main procedures. First, we implement a real-time partitioning of the arterial based on both temporal and spatial characteristics of available spaces beyond the queue of each link, which enables us to identify critical groups of links where long queues or even queue spillovers are present. Second, as soon as at least one critical group of links exists, we trigger a signal control strategy on the whole arterial whose objective is to decrease accumulation in the critical group(s) by adjusting duration of signal phases at the entrance and exit intersections of each group. The key idea with clustering is to split the control problem into smaller sized decentralized control problems.

The proposed arterial traffic control system is tested through simulation on San Pablo Avenue, a real-world 11-intersections congested arterial in Berkeley, CA. The next section presents the primary results for real-time arterial partitioning. We then present the methodology of the arterial signal control strategy.

QUEUES SPILLOVERS REAL-TIME IDENTIFICATION ALONG AN ARTERIAL

A reliable and effective detection of development of long queues in arterials is a prerequisite for the spillover prevention or mitigation of its impacts on traffic. Given the maximum queue length of the preceding cycles in each arterial link, we introduce a model, which enables us to detect critical links or group of links where long queues or queue spillovers are present at each cycle.

For each link j and cycle i, the empty space available (veh/lane) behind the back of the queue $S(j, i)$ can be obtained from the measurement of maximum queue length and the link length. Let us denote $space_{min}$ the corresponding threshold, which below that there is a high possibility of queue spillover occurrence during the next cycle. Detection only based on one preceding cycle data, might lead to overreaction in the control procedure due to ephemeral queue detection. In addition, urban traffic dynamics are stochastic and can significantly vary cycle by cycle. Thus, in order to capture the fundamental characteristics of queue length, we propose to take into account the average of $S(j, k)$

for several previous cycles in order to capture long queues and queue spillovers phenomenon with higher reliability. Let m denotes the number of preceding cycles we consider (from cycle i) to decide whether we should do a partitioning for cycle i+*1.* The main steps of the algorithm are elaborated below.

1- Loop over the time period i from $i = m$
    2- Loop over the arterial link j
        3- If $\frac{1}{m}\sum_{k=i-m+1}^{i} S(j,k) \leq space_{min}$
            4.1- If $\frac{1}{m}\sum_{k=i-m+1}^{i} S(j+1,k) > space_{min}$
                Append j/j+1 intersection as the front of one critical group for time i+1
            4.2- If $\frac{1}{m}\sum_{k=i-m+1}^{i} S(j-1,k) > space_{min}$
                Append j-1/j intersection as the back of one critical group for time i+1
        4- Else End
    5- End
6- End

We evaluate the clustering procedure via micro-simulation in San Pablo Avenue, CA. This study site consists of 11 links with various lengths and time-varying demand. The outcome of clustering algorithm is depicted in Figure 1 where red lines represent the front intersection of critical groups and blue lines represent the back intersection of critical groups. In addition, Figure 1 illustrates the time-space contour plot of available free space, which is regarded as an indicator of queue spatial extent.

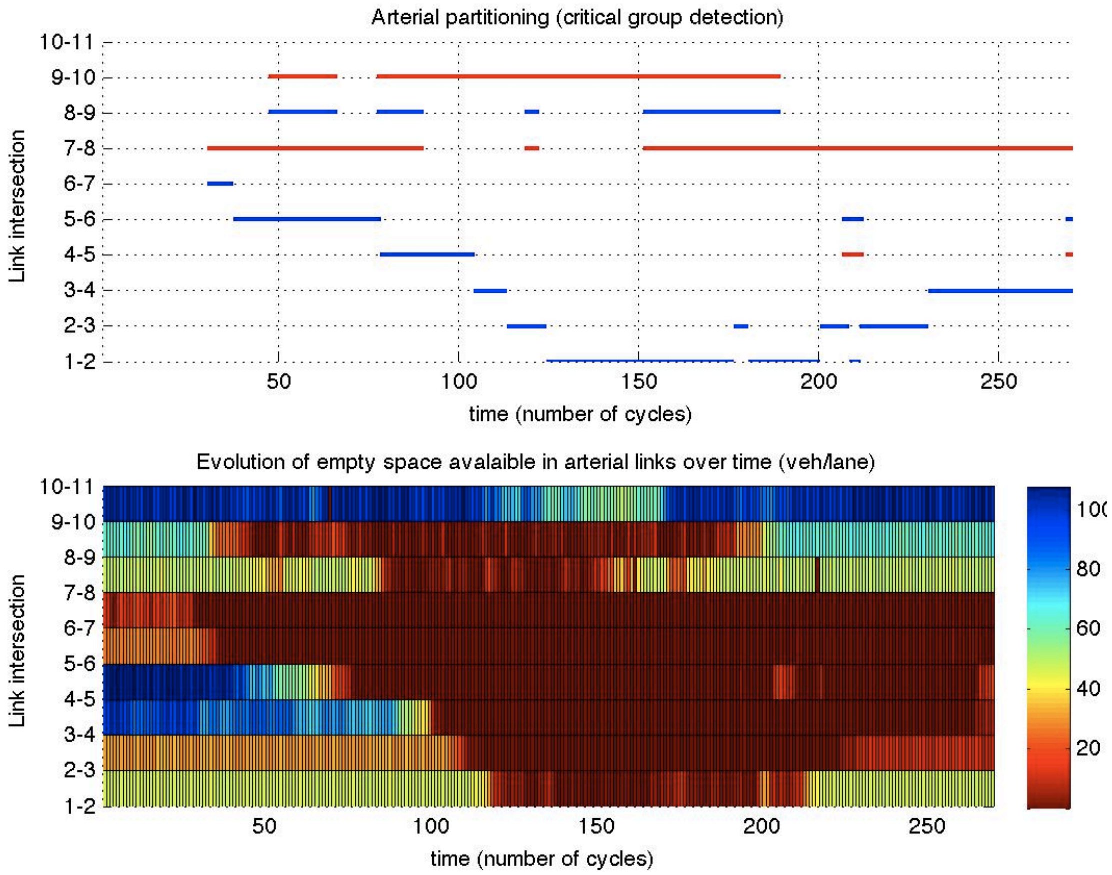

Figure 1: Arterial's partitioning results with *$space_{min}$=8 and m=4* (top), time-space diagram of empty space available in each link (bottom)

The use of m preceding cycles to smooth the partitioning evolution over time might increase the latency of signal control effectiveness. Thus, to compensate this delay time one should increase the $space_{min}$ threshold to detect early enough the long queue phenomenon. We analyze the sensitivity of clustering procedure to $space_{min}$ and m

parameters and the optimal trade-off has been found for $space_{min} = 8$ and $m = 4$. The clustering procedure reproduces accurately the propagation of queue spillover toward upstream as we can see with the blue line moving upstream up to intersection 2-3. Another long queue is detected in link 9 and spillback upstream in link 8 and at some times in link 7 such that this critical group merges with the first one.

SIGNAL CONTROL STRATEGY

The signal control strategy is based on the link groups resulting from the arterial partitioning. At the beginning of each cycle, we model the arterial as a succession of groups whose traffic inputs and outputs are interdependent. Signal control is allowed only at the entrance and exit intersections of each group called *Control intersections*. Figure 2 illustrates the variables in the arterial model: traffic inputs and outputs q_k are *control variables* whereas traffic inputs and outputs d_k are *disturbances* because they are not controlled. Let $n(i,k)$ denotes the vehicle accumulation in links belonging to group k during cycle i, we have:

$$
\begin{aligned}
\dot{n}(i,1) &= \sum d_1^{in} - \sum d_1^{out} - q_1^{out,th+rt} - q_1^{out,lt} \\
\dot{n}(i,k) &= \sum d_k^{in} - \sum d_k^{out} + q_{k-1}^{out,th} + q_{k-1}^{in,lt+rt} - q_k^{out,th+rt} - q_k^{out,lt} \\
\dot{n}(i,n) &= \sum d_n^{in} - \sum d_n^{out} + q_{Cn-1}^{out,th} + q_{Cn-1}^{in,lt+rt} - q_{Cn}^{out,th+rt} - q_{Cn}^{out,lt},
\end{aligned}
$$

where d_k flows can be estimated with loop detectors located in crossing links and q_k can be controlled by adjusting the phase duration of the control intersection. For instance, a very good approximation of $q_{k-1}^{out,th}$ in congested conditions is $q_{k-1}^{out,th} = s_{k-1} * g_{k-1}^{th}$ where s_{k-1}^{th} is the saturation flow for the through movement and g_{k-1}^{th} is the effective green phase duration for the through direction.

<u>For each critical group of links c</u>, which has been detected at the end of cycle *i*, the objective of the controller for the next cycle, *i+1*, is $\dot{n}(i+1,c) \leq 0$. More details of the control logic and results will be presented in the full paper.

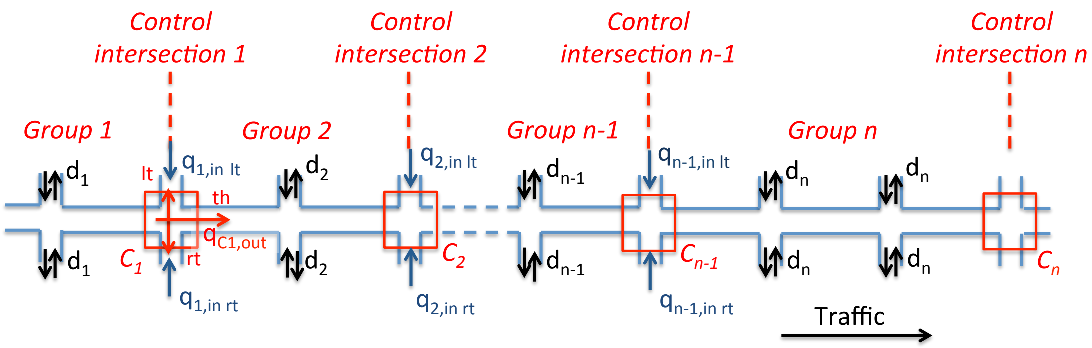

Figure 2: Arterial Signal Control framework for cycle *i*

CONCLUSION

The proposed methodology has developed an integration of two subsystems (observation and control) to mitigate the effect of queue spillovers along signalized arterials. Based on queue lengths measurements from the prevailing loop detectors or probe vehicle technologies, we introduce a clustering algorithm to detect critical link or group of links where long queues or queue spillovers occur. This results in a partitioning of the arterial, from which we trigger the signal control. The control system limits the vehicle accumulation in critical link groups by manipulating the split of phases of signals at entrance and exit intersections of each link group. The performance of this control strategy will be comprehensively evaluated through simulation.

REFERENCES

Geroliminis N. and Skabardonis A., Identification and analysis of queue spillovers in city streets networks. *IEEE Transactions on Intelligent Transportation Systems*, No. 99, 2011,pp. 1-9.

Christofa E., Argote J. and Skabardonis A., Arterial queue spillback detection and signal control based on connected vehicle technology, *Transportation Research Board*, No. 13-4903, 2012.