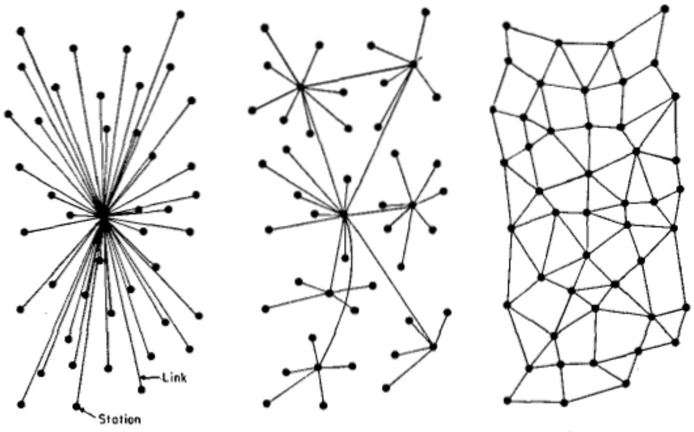
Control strategies for network efficiency and resilience with route choice

Andy H. F. Chow [*]
Rui Sha

Centre for Transport Studies, University College London, Gower Street, London WC1E 6BT, UK

This paper investigates different designs of control systems for managing network efficiency and resilience with consideration of real time variations and uncertainties in traffic flows and travel behaviour. It is understood that urban traffic networks are complicated systems that involve dynamics and interaction of a vast number of components including different types of junctions, vehicle classes, and road users. It is expected that efficiency and resilience of road networks can be significantly improved by coordinating all components under a centralised framework. Nevertheless, the complexity of urban networks makes it difficult to be managed by a single central system. This calls for a number of research effort on the more parsimonious and 'easy-to-run' distributed control systems in which the local components can derive their own control actions (see e.g. [1], [2], [3], [4]) It is understood that a centralised system will theoretically be able to derive a more effective policy than its distributed counterparts with better coordination. Nevertheless, the computational time for deriving such global optimal control plan increases exponentially with the size of the underlying transport networks and would eventually become intractable. One would argue that the computational efficiency gained by adopting distributed systems will have to come at the expense of the overall system-wide performance. However, a number of recent studies have suggested that the performance of a well-designed distributed system would not be significantly outperformed by a centralised one ([2], [3], [5]).



(a) (b) (c)

Fig. 1—(a) Centralized. (b) Decentralized. (c) Distributed networks.

This study formulates different control systems ranging from centralised, decentralised, to distributed for urban network traffic control (see Figure 1). In a centralised system, all traffic information will be sent to a central controller or agent which is responsible for deriving and implementing all control actions. Based upon the store-and-forward model [6], we present the TUC urban traffic control system [7] as a representative of the centralised system. In TUC, the green splits are derived from a centralised linear quadratic regulator (LQR) which aims to minimise overall network queues. The underlying store-and-forward traffic model in the LQR formulation updates the traffic queues every signal cycle. As a centralised regulator, TUC considers global queue distribution when deriving and implementing its control actions. Following [8], in this study we also demonstrate a decomposition of the original TUC formulation into a series of decentralised problems using the alternative direction method of multipliers (ADMM). We compare the performance of this decentralised version

[*] Correspondence: *andy.chow@ucl.ac.uk*

of TUC with respect to the original centralised one over different network and network settings. Moreover, unlike the centralised control systems which make all control actions within the network of interest by itself, the distributed systems decompose the global problem into smaller 'sub-problems' and delegate the control decisions to local controllers. Consequently, the distributed systems are able to derive control plans with much shorter computational time and effort. For the distributed counterparts, we consider the recently established max-pressure (MP, [1]) control strategy. As a distributed system, the MP controller does not require knowledge of global network inflow [1]. The MP controller adjusts local green splits based upon both upstream and downstream local queue length measurements at each intersection.

To evaluate the performances of the control systems above in different settings, the control systems are implemented on the SUMO simulation platform over different network topologies including one-dimensional arterial and two-dimensional grid networks. SUMO (Simulation of urban mobility, [9]) is an open-source stochastic microscopic traffic flow model that is able to capture fine details and stochastic nature of traffic dynamics. It also provides an application program interface (API) that can incorporates various external features including different kinds of signal control schemes and dynamic traffic routing and assignment algorithms. The performance of the control systems will be measured in terms of the associated network delays under their control. In addition to different networks, we also investigate performances of the control systems with different levels and spatial distributions of traffic demand. The control systems presented in the previous section are implemented into SUMO through its MATLAB API. In addition to efficiency, the resilience of each control system will also be tested by iteratively removing critical links in the network. A control system is regarded as more resilient than the other if its performance (i.e. delay) is less affected before and after removal of the critical links [10]. To capture the likely responses of drivers with respect to the variations in prevailing traffic condition, we further implement a dynamic routing algorithm to represent the route choice behaviour of drivers with respect to the prevailing traffic conditions and signal settings. The routing algorithm operates as follows: given an origin-destination matrix, each vehicle will first proceed following the shortest path collecting its origin-destination pair. As traffic congestion building up in the network, the travel times on each link will be updated every second. Following the updates of the link travel times, the vehicles will re-calculate the shortest path and revise its routing decision whenever it reaches a node accordingly. Given the dynamic nature of traffic and the relatively short simulation horizon, there is no guarantee that the network could converge to the traditional dynamic user equilibrium within the simulation horizon. Nevertheless, such iterative routing process has been shown to be a more realistic representation of short-term travel behaviour and it is an important feature when one aims to investigate the network behaviour with respect to unexpected disruptions [11]. Figure 2 shows some preliminary results in which Figure 2a shows the performance (network delays) of the four control systems: centralised TUC, decentralised (TUC_D), cyclic max-pressure control (MP (BP), [4]), and max-pressure controller (MP), which represent different degree of (de-)centralisation, on an one-dimensional arterial where there is no route choice. Figure 2b shows results from a similar experiment setting on a two-dimensional 3-by-3 grid network where drivers can adjust their travel route with respect to prevailing traffic conditions. The value of γ represents the degree of network-wide saturation in each case. It can be seen that decentralised / distributed systems (e.g. MP) could indeed outperform their centralised counterparts when there is degrees of freedom (e.g. route choice) allowed in the network. This study contributes to the state-of-art of traffic control design.

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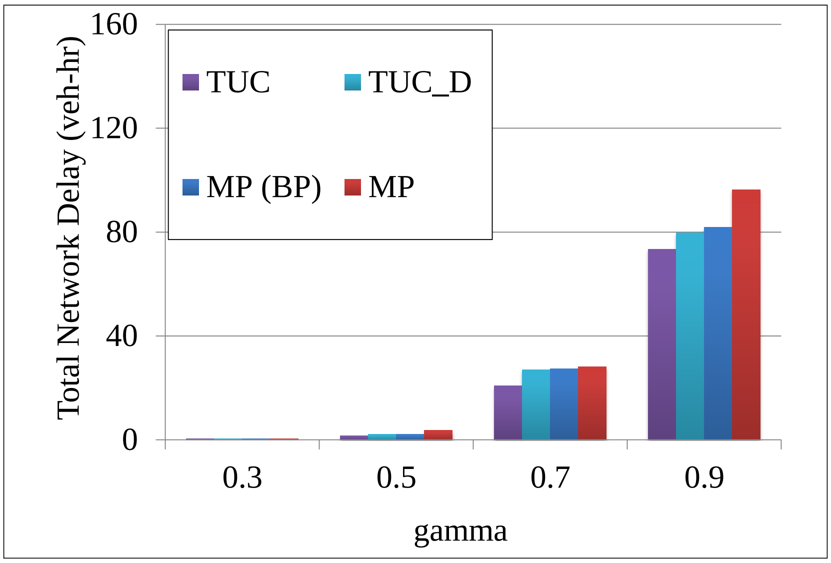
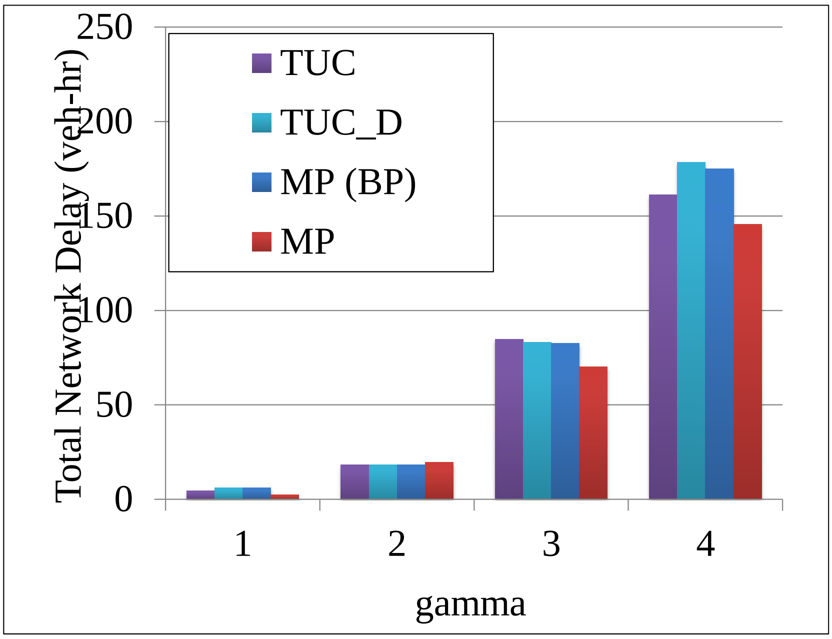


a) One-dimensional arterial



b) Two-dimensional grid network

Figure 2 Performance of different control settings

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