Scaling in the Recovery of Cities in Special Events

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The objective of this work is to combine the multilayer construction of multimodal transport networks with models of packets running through the network. The complex networks analysis and the multilayer approach has been used to study public transport networks but the resilience and performance of this networks under the real demand and special events still needs to be studied. Different routing protocols give more information about the structure and robustness of this networks. When modelling the use of the public transport systems the shortest path approach fails to simulate the real behaviour due to the high path degeneration, with several shortest paths with low difference in their length. We will model the normal activity of a public transport network under a shortest path routing protocol without information and with full information. While the shortest path routing protocol give rise to a few important hotspots in the city, in case with full information many smaller hotspots appear as a consequence of a higher distribution in the usage of paths.

Once we have tested how the models work, we study the recovery of public transport networks under perturbations. We introduce a huge amount of packets or individuals in the network and study the time of recovery of the network. We will use the previous model on urban mobility to simulate the normal use of the public transport system and study their recovery against perturbations, depending on the amount of agents introduced and the place in the city. First of all we divide a city in areas of 200m x 200m, where we will introduce the perturbations. In this section we will also test two routing protocols and their effect on the recovery of the network. As expected both routing protocols give rise not only to different times of recovery but also to different shapes in the evolution of individuals in the network. In the case where they follow the shortest paths (figure 1.a) we observe a linear recovery with time in a log-log plot. In fact the link with higher betweenness will dominate and the total time of recovery will depend on the load per second of that link. In the case of the adaptative routing with local information (figure 1.b) the difference on the time of recovery when we include more agents is lower specially for higher values, this is due to walking between the source and destination. Basically the different packets use all the routes until all of them collapse and the optimal time is obtained by walking. Interestingly more all the scaling exponents in a log-log plot are between 0.25 and 0.5 depending on the zone where we introduce this perturbation. This scaling exponent is related to the effective dimension of the network, in fact the exponent is equal to the inverse of the effective dimension. This dimension is modified by the appearance of different transport modalities with different speeds and capacities. We proof that the scaling exponent is 0.5 for a regular lattice and for the public transport network with only one transport modality which is equivalent to the regular lattice.

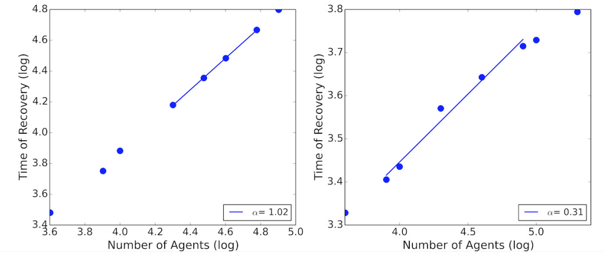

Figure 1: Time of recovery depending on the routing protocol and the number of agents introduced in the perturbation in log-log scale. a) shortest path routing protocol b) adaptative routing protocol with local information.

It is also interesting to analize how the recovery times change when we introduce the same perturbation in different places of the city. Again we will begin studying the simplest case where all the agents follow the shortest path, this case allows us to calculate the time of recovery. The line that will dominate the recovery will be given by the rate of the betwenness and the load per second. Basically in the case where all lines have the same capacity and frequency, the congested line that should dominate is the one with higher betweenness.

The interesting case is however when the individuals use an adaptative routing protocol because the full topology of the networks comes into play. In this case we expect that the center of the city, where there is a higher density of lines, will be the place with faster recovery of the network and the recovery times will increase as we go further from the center. As each line has a load per second, beginning at the point where the perturbation is introduced, increasing the distance that an individual will walk we observe an increase of the load per second as the access to lines increases. We proof time of recovery of the different zones will be given between the point of equilibrium between walking time and total capacity in the area walked.