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Quality of Service of Transportation Networks: A Hybrid Measurement of Travel Time and Reliability

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Abstract : In a transportation network, travel time refers to the transmission time from source node to destination node, whereas reliability refers to the probability of a successful connection from source node to destination node. With an increasing emphasis on quality of service (QoS), both performance indexes are significant in the design and analysis of transportation systems. In this work, we extend the well-known flow network model for transportation networks so that travel time and reliability are integrated into the QoS measurement simultaneously. In the extended model, in addition to the general arc capacities, each intermediate node has a time weight which is the travel time for per unit of commodity going through the node. Meanwhile, arcs and nodes are treated as binary random variables that switch between operation and failure with associated probabilities. For pre-specified travel time limitation and demand requirement, the QoS of a transportation network is the probability that source can successfully transport the demand requirement to destination while the total transmission time is under the travel time limitation. This work is pioneering, since existing literatures that evaluate travel time reliability via a single optimization path, the proposed QoS focuses the performance of the whole network system. To compute the QoS of transportation networks, we first transfer the extended network model into an equivalent min-cost max-flow network model. In the transferred network, each arc has a new travel time weight which takes value 0. Each intermediate node is replaced by two nodes u and v, and an arc directed from u to v. The newly generated nodes u and v are perfect nodes. The new direct arc has three weights: travel time, capacity, and operation probability. Then the universal set of state vectors is recursively decomposed into disjoint subsets of reliable, unreliable, and stochastic vectors until no stochastic vector is left. The decomposition is made possible by applying existing efficient min-cost max-flow algorithm. Because the reliable subsets are disjoint, QoS can be obtained directly by summing the probabilities of these reliable subsets. Computational experiments are conducted on a benchmark network which has 11 nodes and 21 arcs. Five travel time limitations and five demand requirements are set to compute the QoS value. To make a comparison, we test the exhaustive complete enumeration method. Computational results reveal the proposed algorithm is much more efficient than the complete enumeration method. In this work, a transportation network is analyzed by an extended flow network model where each arc has a fixed capacity, each intermediate node has a time weight, and both arcs and nodes are independent binary random variables. The quality of service of the transportation network is an integration of customer demands, travel time, and the probability of connection. We present a decomposition algorithm to compute the QoS efficiently. Computational experiments conducted on a prototype network show that the proposed algorithm is superior to existing complete enumeration methods.

Keywords : quality of service, reliability, transportation network, travel time
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