Claims

1. A computer system (100) for providing SPaT (Signal Phase and Timing) messages to a vehicle (401, 501) wherein the SPaT messages include reliable timing parameters to influence the operation of the vehicle, the computer system (100) comprising:

an interface component (110) configured to receive switching state data from one or more traffic lights (S1 to S4) wherein switching state data (SD1) of a particular traffic light includes signal states comprising at least a pass-state (SD1p) and a stop-state (SD1s) of the particular traffic light at respective sampling time points, and further configured to provide a SPaT message (402) to the vehicle (401, 501);

a signal analyzer component (140) configured to perform a sequence of analysis steps for prediction intervals having the same length as the sampling intervals by:

identifying the current signal state (SD1s, SD1p) of the one or more traffic lights (S1 to S4);

deriving, from a statistical model (130) trained on the basis of historic state transitions of the one or more traffic lights, probabilities for future state transitions from the current state into a different state for one or more future prediction intervals;

determining a minimum end time point as the start of the nearest future prediction interval where the probability of the current state falls below a predefined first threshold value, the minimum end time point being the earliest point in time for a state transition from the current state to the different state;

checking (1500) if a maximum end time point can be identified by checking if the probability of the different state exceeds a predefined second threshold value in a respective prediction interval; and

if the maximum end time point can be identified, determining the maximum end time point as the start of a further nearest prediction interval where the probability of the different state exceeds the predefined second threshold value, the maximum end time point being the latest point in time for a state transition from the current state to the different state wherein the maximum end time point occurs after the minimum end time point; and

a message composer component (150) configured to compose the SPaT message including the determined minimum end time point, and if the maximum end time point is determined, to compose the SPaT message (402) including the determined maximum end time point.

2. The computer system of claim 1, wherein,

if the probability of the different state exceeds a predefined second threshold value, the signal analyzer (140) is further configured to:

estimate a likely time and a corresponding confidence value for the particular state transition; and

the message composer (150) further configured, if the maximum end time is determined, to compose the SPaT message (402) including the estimated likely time and the corresponding confidence value.

3. The computer system of claim 1 or 2, further comprising:

a training module configured to generate and train the statistical model (130) based on switching state data (SD1) received from the one or more traffic lights.

4. The computer system of any of the previous claims, wherein the statistical model is a Hidden Markov Model (HMM) representing potential state transitions of the one or more traffic lights with respective probabilities within a switching state data cycle.

5. The system of claim 4 when dependent on claim 3, wherein the training module (120) is configured to generate the Hidden Markov model (HMM) by:

detecting the light signal state in each sampling time point;

checking if the detected state already exists as a hidden state (h0) in the Hidden Markov Model;

if the corresponding hidden state transition already exists, selecting a hidden state by the destination of the hidden state transition;

if the hidden state transition is not existing but the received state data can be explained by a particular existing state of the Hidden Markov Model, then selecting the particular existing state;

if the hidden state transition is not existing and a corresponding hidden state is not in the Hidden Markov Model, creating a new hidden state and selecting the new hidden state;

updating the before-hidden-state with the latest-hidden-state and the latest-hidden-state with the selected hidden state,

if no transition exists between the before-hidden-state and the latest-hidden-state, creating a transition between the before-hidden-state and the latest-hidden-state, and

incrementing a hidden state transition counter between the before-hidden-state and the latest-hidden-state.

6. The system of claim 5, further comprising:

a probability module (141) configured to determine the probability for a state transition based on an evaluation of all hidden state transition counter values between two subsequent cycle time points in the Hidden Markov Model (HMM).

7. The computer system of any of the claims 1 to 3, wherein the statistical model (700) includes averaged probabilities of one or more signal states for each sampling interval within a switching state data cycle, and wherein the training module (120) is configured to generate the statistical model (700) by:

recording a statistically relevant sized sample of switching state data cycles;

identifying, for each cycle in the sample of switching state data cycles, a cycle start time; and

deriving probabilities for at least one signal state for the sampled switching state data having the same time offsets from the respective cycle start times.

8. A computer-implemented method (1000) for providing SPaT (Signal Phase and Timing) messages to a vehicle wherein the SPaT messages include reliable timing parameters to influence the operation of the vehicle, the method comprising:

receiving (1100) switching state data from one or more traffic lights wherein switching state data of a particular traffic light includes signal states comprising at least a pass-state and a stop-state of the particular traffic light at respective sampling time points;

identifying (1200) the current signal state of the one or more traffic lights;

deriving (1300), from a statistical model trained on the basis of historic state transitions of the one or more traffic lights, probabilities for future state transitions from the current state into a different state for one or more future prediction intervals, the prediction intervals having the same length as the sampling intervals;

determining (1400) a minimum end time as the nearest future prediction interval where the probability of the current state falls below a predefined first threshold value, the minimum end time point being the earliest point in time for a state transition from the current state to the different state;

checking (1500) if a maximum end time point can be identified by checking if the probability of the different state exceeds a predefined second threshold value in a respective prediction interval;

if the maximum end time point can be identified, determining (1600) the maximum end time point as the start of a further nearest prediction interval where the probability of the different state exceeds the predefined second threshold value, the maximum end time point being the latest point in time for a state transition from the current state to the different state, wherein the maximum end time point occurs after the minimum end time point;

composing (1800) a SPaT message including the determined minimum end time, and if the maximum end time point is determined, including the determined maximum end time point; and

providing (1900) the composed SPaT message to the vehicle.

9. The method of claim 8, further comprising:

if the probability of the different state exceeds a predefined second threshold value,

estimating (1700) a likely time and a corresponding confidence value for the particular state transition, and composing (1800) the SPaT message further including the determined maximum end time, the estimated likely time and the corresponding confidence value.

10. The method of claim 8 or 9, wherein the statistical model is a Hidden Markov Model representing potential state transitions of the one or more traffic lights with respective probabilities within a switching state data cycle.

11. The method of claim 10, wherein the method further comprises:

detecting (5010) the light signal state in each sampling time point;

checking (5120) if the detected state already exists as a hidden state in the Hidden Markov Model;

if the corresponding hidden state transition already exists, selecting (5131) a hidden state by the destination of the hidden state transition;

if the hidden state transition is not existing but the received state data can be explained by a particular existing hidden state of the Hidden Markov Model, then selecting (5133) the particular existing state;

if the hidden state transition is not existing and a corresponding hidden state is not in the Hidden Markov Model, creating (5132) a new hidden state and selecting the new hidden state;

updating (5210) the before-hidden-state with the latest-hidden-state and the latest-hidden-state with the selected hidden state;

if no transition between before-hidden-state and the latest-hidden-state exist, creating (5224) a transition between before-hidden-state and the latest-hidden-state; and

incrementing (5226) a hidden state transition counter between the before-hidden-state and the latest-hidden-state.

12. The method of claim 11, wherein the probability for a state transition is determined based on an evaluation of all hidden state transition counter values between two subsequent cycle time points of the Hidden Markov Model (HMM).

13. The method of claim 8 or 9, wherein the statistical model includes averaged probabilities of one or more signal states for each sampling interval within a switching state data cycle.

14. The method of claim 13, further comprising generating the statistical model by:

recording a statistically relevant sized sample of switching state data cycles;

identifying, for each cycle in the sample of switching state data cycles, a cycle start time; and

deriving probabilities for at least one signal state for the sampled switching state data having the same time offsets from the respective cycle start times.

15. A computer program product that, when loaded into a memory of a computer system for determining state changes of a further system and executed by at least one processor of the computer system, performs the steps of the computer-implemented method according to any of the claims 8 to 14.