settings.Two well-known systems, SCATS (Sydney Coordinated Adaptive Traffic System) [1] and SCOOT (Split, Cycle and Offset Optimization Technique) [10], follow this methodology. These systems have detectors placed on every approach to an intersection, usually at a single point of the road or at two points for calculating the size of the queue. Thus, they cannot get accurate data when this queue grows beyond the length between detectors, or the link is oversaturated. Since they use a model based especially on occupancy, they also have difficulties in differentiating between high flows or intersection stoppage.

A further optimization of adaptive traffic lights was proposed in [6], where an adaptive traffic light system based on wireless communication between vehicles and a wireless controller node placed at the intersection. As compared to the approaches mentioned previously, the adaptive traffic light system includes more information (e.g., vehicles' positions and speeds) in the signal decision process. As a result, this approach overcomes the shortcomings of traditional systems that can result from the fixed location of the detectors.

Our approach uses a new self-organizing traffic paradigm whereby the cars themselves act as mobile sensors of the traffic state, and resolve the conflicts at intersections *without* the need for external traffic lights. This approach is enabled just by the vehicle-to-vehicle communication capability of cars based on the DSRC standards at 5.9 GHz band. It is important to note that none of these previous studies employ the approach proposed in our paper; namely, use of in-vehicle traffic lights based on V2V communications for resolving the conflicts at intersections for determining the "right of way" in a seamless manner.

3. SYSTEM DESIGN

The implementation of the in-vehicle virtual traffic lights (VTL) system is based on the following assumptions:

- All vehicles are equipped with DSRC devices;
- All vehicles share the same digital road map;
- All vehicles have a global positioning system (GPS) device that guarantees global time and position synchronization with lane-level accuracy.
- The security, reliability, and latency of the wireless communication protocol are assumed to be adequate for the requirements of the VTL protocol.

The principle of operation of the proposed scheme is relatively simple and is illustrated in Fig. 2. Each vehicle has a dedicated Application Unit (AU) which maintains an internal database with information about intersections where a virtual traffic light can be created. When approaching such intersections, the AUs check whether there is a virtual traffic light running that must be obeyed, or if there is a need to create one as a result of perceiving crossing conflicts between approaching vehicles (see Fig. 2(a)).

The detection of the need to create a VTL uses the beaconing and location tables features of VANET geographical routing protocols.It is assumed that each node maintains a location table containing information about every node in its vicinity, that is constantly updated through the reception of new beacons. With the assumed lane-level accuracy of the GPS devices, this table can be queried to infer crossing conflicts. If it is necessary to create a VTL, then all the

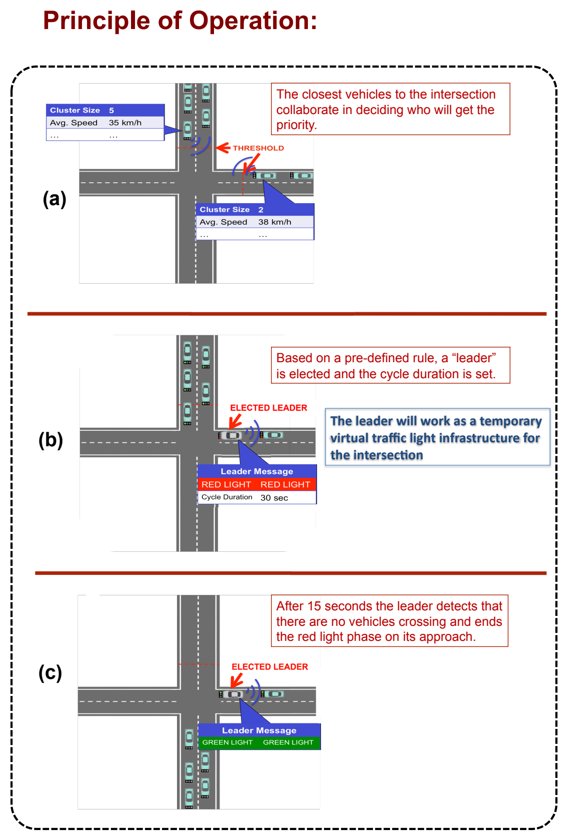

Figure 2: The principle of operation of the proposed in-vehicle traffic light scheme at an intersection of a Manhattan Street topology.

vehicles approaching the intersection must agree on electing one of them to become the *leader*, which will be the responsible for creating the VTL and broadcast the traffic light messages (see Fig. 2(b)). This vehicle will work as a *temporary virtual infrastructure* for the intersection and assume the responsibility of controlling the VTL.

The *leader* vehicle should have two important characteristics: i) be presented with a red light, and thus be stopped at an intersection while leading it; and ii) be the closest vehicle to the intersection center in its own cluster, in order to improve the omni-directional broadcast of the VTL messages to all approaches. We should note that the stopping place of leader vehicles in the VTL protocol is much closer to the center of the intersection than the usual stopping place of cluster leading vehicles in existing physical traffic light systems. As the visual perspective of the traffic light is always perfect through in-vehicle display, we can optimize the omni-directional emission of the radio signal by assigning the stopping place of the *leader* to be as close as possible to the center of the intersection. During the existence of this *leader*, the other vehicles act as passive nodes in the protocol, listening to the traffic light messages and just presenting them to the driver through the in-vehicle displays.

During the VTL lifetime, the leader only commutes its current phase, but the virtual traffic light message remains the same. Once the current phase is finished, the leader changes the virtual traffic light message to apply the next phase. When the green light is in the leader's lane, a new