Over the last decade, wireless networking has advanced significantly, responding to demands for increased flexibility and scale. As a result, new technologies, such as Wi-Fi, WiMAX, LTE and LTE-Advanced, are gradually finding their way in large-scale dense deployments in residential, enterprise and public spaces. Wireless access points are growing almost to a continium while a myriad of wireless devices become embedded in the internet infrastructure and create an environment of unprecedented complexity. The complexity of future networks is expected to increase dramatically as networks become decentralized and boundaries between the protocol layers become obsolete, while at the same time the core, internet network itself moves to a different, distributed "cloud" paradigm. As a result, future wireless networks face four fundamental challenges:

- *Understand the emergent complex structures of large-scale networks.* The interaction between large numbers of nodes gives rise to macroscopic network behavior that often cannot be predicted from the analysis of the behavior of a few entities. Gaining intuition for such emergent properties can help model future networks more efficiently.

- *Adapt to the mandate for distributes wireless network management and control*. In distributed wireless networks, traditional network management methods that rely on centrally controlled optimization are largely inadequate. Instead, appropriate real-time adaptive and distributed methods are required, designed to optimize either a global or several (possibly conflicting) objectives.

- *Respond to the need for real-time large-scale monitoring.* Given the scarcity of resources such as bandwidth and energy and the error-prone wireless medium, partial network state information of limited accuracy may be available to network entities for them to make appropriate management decisions. Obtaining and transporting real-time global network state information at various distances and time scales might be inefficient or infeasible (as in the case of partitioned networks). A systematic methodology for managing network complexity by appropriately acquiring and handling network state information is needed.

- *Address the effects of challenged environments*. Given the expected ubiquity of wireless networks, their design has to take into account harsh environments exhibiting intermittent connectivity, excessive delays, and fast topology changes due to mobolity.

Unfortunately, our current understanding and methods for performing wireless network management are far from being able to address these challenges. This is evidenced by the following mundane examples:

- Spectrum, a primary resource in wireless networks, is managed based on the static pre-allocation of spectrum chunks, and there exists no concrete methodology for spectrum management in a flexible fashion that optimizes spectrum utilization efficiency.

- Spectrum quality monitoring in wireless settings is performed based only on separated measurements of the Signal-to-Interference-and-Noise Ratio (SINR). This neglects important avenues of improvement, such as adaptive and cooperative learning schemes using sophisticated real-time sensing, or by sharing information with nearby locations.
- Wireless coverage and connectivity often experience large fluctuations due to unforeseen events and/or node mobility. Traditional methods, such as increasing the density of wireless access points or base station towers, obviously cannot be effective in such cases, although dynamic channel/transmit power readjustments and/or more delay tolerant designs could suffice.
- In legacy IEEE 802.11 WLANs, but also in other classes of wireless networks, there is no systematic procedure to diagnose faults and react accordingly, and the usual procedure is to manually configure access points or do ad hoc heuristics in the hope of resolving the problem.

- TCP-based network traffic congestion is not effective in the wireless regime, despite its widespread application there, since TCP cannot distinguish congestion feedback data from wireless channel errors.

It is rapidly becoming clear that a radical paradigm shift is needed in the process of accessing and processing information at a network level, towards providing self-awareness, self-organization and self-coordination of wireless networked entities. Self-awareness refers to the crucial capability of *acquiring* the network status, *reasoning*, and *realizing certain reactions* based on the extracted network information, in order to achieve some specified objective in the presence of inaccurate and incomplete information. Network status information can be vastly diverse, such as information on user migration, performance measures such as the values of key performance indicators, social structures, patterns of use, resource availability, topology information, and traffic load spatial and temporal patterns.
Self-organization or self-coordination refers to the process of incorporating reasoning and self-awareness into the network management control loop.

Self-organization can be realized in two distinct modes. In the first, the optimization criteria are *individual*, with autonomous nodes interacting and possibly cooperating, but driven by selfish motives. In the second, nodes can collaborate with a common *global* objective. In this case, self-organization should amount *to judiciously compensating for partial network state information*

through
intelligent feedback collection and sophisticated information fusion techniques.
Thus, the available information can be utilized in the sense of some optimization criteria. Such criteria are determined by the network operational objectives and may refer either to information transport per se (e.g., transport capacity, delay, energy / bandwidth efficiency) or some inference related objective.

The wireless resource limitations and the volatility of wireless channels make network state information inherently inaccurate, outdated and unreliable. This, together with the increasing complexity of envisioned wireless networks pose an important challenge for self-organizing wireless networks. Thus, functionalities should be developed, which describe the network status in a stochastic fashion. Alternatively, network state-oblivious operating modes should be developed.

In the CROWN project, we advocate that a fresh, clean-slate approach should be adopted**.** We aim to understand the fundamental tradeoffs in building and efficiently exploiting self-awareness and self-coordination in the control of wireless networks. The approach is cross-disciplinary, since it spans a wide range of areas such as statistical learning, game theory, optimal control, statistical physics and wireless networking. Our work will move along the following axes:

- First, we focus on cases there the wireless network control loop involves uncoordinated (hence *autonomic*) wireless node interaction. The ultimate wireless network operational regime is determined either by the conflicting interests of nodes and the inherent competition incurred by limited resources, or by the natural inclination of nodes to join forces and engage in coalitions whenever this is mutually beneficial for all of them.
- Second, we focus on cases there the wireless network involves *coordinated* mechanisms, with aim to optimize a global metric. This optimization is achieved through distributed interaction between nodes.

- Third, we will exemplify the methods above in extremely *challenged network environments* with intermittent connectivity. The methods will be used for quantifying fundamental performance limits in terms of managing wireless resources for optimizing wireless network performance, i.e., maximizing transport capacity, minimizing transport latency, and minimizing energy expenditure.