Brussels, 23 June 2017

COST 039/17

DECISION

Subject: **Memorandum of Understanding for the implementation of the COST Action "European Network for Game Theory" (GAMENET) CA16228**

The COST Member Countries and/or the COST Cooperating State will find attached the Memorandum of Understanding for the COST Action European Network for Game Theory approved by the Committee of Senior Officials through written procedure on 23 June 2017.

MEMORANDUM OF UNDERSTANDING

For the implementation of a COST Action designated as

COST Action CA16228
EUROPEAN NETWORK FOR GAME THEORY (GAMENET)

The COST Member Countries and/or the COST Cooperating State, accepting the present Memorandum of Understanding (MoU) wish to undertake joint activities of mutual interest and declare their common intention to participate in the COST Action (the Action), referred to above and described in the Technical Annex of this MoU.

The Action will be carried out in accordance with the set of COST Implementation Rules approved by the Committee of Senior Officials (CSO), or any new document amending or replacing them:

a. "Rules for Participation in and Implementation of COST Activities" (COST 132/14);
b. "COST Action Proposal Submission, Evaluation, Selection and Approval" (COST 133/14);
c. "COST Action Management, Monitoring and Final Assessment" (COST 134/14);
d. "COST International Cooperation and Specific Organisations Participation" (COST 135/14).

The main aim and objective of the Action is to i) To provide accurate models for strategic interaction on large networks. ii) To develop low-complexity algorithms to solve these models. iii) To evaluate the performance and robustness of large-scale networks. iv) Develop game theoretic models for industrial applications in telecommunication and traffic networks. This will be achieved through the specific objectives detailed in the Technical Annex.

The economic dimension of the activities carried out under the Action has been estimated, on the basis of information available during the planning of the Action, at EUR 72 million in 2016.

The MoU will enter into force once at least five (5) COST Member Countries and/or COST Cooperating State have accepted it, and the corresponding Management Committee Members have been appointed, as described in the CSO Decision COST 134/14.

The COST Action will start from the date of the first Management Committee meeting and shall be implemented for a period of four (4) years, unless an extension is approved by the CSO following the procedure described in the CSO Decision COST 134/14.

TECHNICAL ANNEX

OVERVIEW

Summary
With the rapid advancement of technological innovations, modern societies rely more and more on the proper functioning of complex networks (i.e., social, telecommunication and transportation networks). Since the state and the dynamics of these networks are determined by independent decision makers, a solid understanding, control and optimization of such networked systems constitutes a major challenge for modern societies.

Game theoretic concepts are nowadays used in the analysis of networked systems, such as the computation of traffic equilibria in large-scale transportation networks, the prediction of content popularity in social networks and online services, and the analysis of the spreading of diseases and epidemics. Since there are many applications from different fields exhibiting similar network structures (e.g., biological, technological and social networks) and each of these applications has field-specific characteristics, our Action needs to bring together researchers from different fields of science, such as, applied mathematics, algorithmic computer science, engineering and economics.

The key objective of this Action is to facilitate interactions and collaborations between different groups of game theorists, to provide game theoretic expertise to industrial partners, and to establish a large and vibrant interconnected community of excellent scientists in these different fields. This Action will be the first European network where computer scientists, applied mathematicians, economists, and operations researchers will join forces on problems with significant technological and socio-economic impact. On a meta-level, the aim is to create a broad community of game theorists across Europe and at every stage of their career and to facilitate contact with stakeholders.

Areas of Expertise Relevant for the Action	**Keywords**
● Mathematics: Control theory and optimization ● Computer and Information Sciences: Theoretical computer science and formal methods ● Economics and business: Microeconomics, institutional economics	● Game Theory ● Networks ● Algorithms ● Economic Engineering ● Mathematical Programming

Specific Objectives
To achieve the main objective described in this MoU, the following specific objectives shall be accomplished:

Research Coordination
● To initiate novel transdisciplinary research links with academia and industrial stakeholders.
● To develop novel theory and methodology in important fields of game theory and its applications.
● To seed future research projects, to channel efforts and maximize efficiency.
● To identify pressing research needs in game theory, modeling and algorithmic analysis.
● Develop practical and efficient algorithms for resource allocation problems in 5G wireless networks.
● Provide a software library for effective congestion control for traffic planners.
● Develop an algorithmic framework for evolutionary games on graphs.
● Provide polynomial-time algorithms for graph games with stochastic transitions.
● Develop a computational environment for continuous time games.

Capacity Building

● Create an excellent network of researchers in Europe with lasting collaboration beyond the lifetime of the Action.
● Transfer knowledge in terms of expertise, scientific tools and human resources across the disciplines and between academia and industry.
● Establish an inclusive research community for game theoretic research to promote Early Career Investigators (ECIs) and increase their visibility.
● To achieve geographic and demographic diversity with special attention to gender balance and COST Inclusiveness Target countries throughout the Action
● Prepare competitive EU researchers for a fruitful career in an international environment through intensive use of Short Term Scientific Missions (STSM), and joint educational programs with industrial partners.
● Disseminate the results of the Action activities to the scientific community and to the general public.

1) S&T EXCELLENCE

A) CHALLENGE

I) DESCRIPTION OF THE CHALLENGE (MAIN AIM)

With the rapid advancement of emerging communication technologies, modern societies rely more and more on the proper functioning of complex networks (e.g., social, telecommunication and transportation networks). Additionally, modern communication devices allow decision makers to obtain information on relevant quantities almost instantaneously. This combination of complex interactions and high-frequency decision-making, challenges the perceived paradigm used by game theorists to study strategic interactions in social, economic and technological systems. Since the state and the dynamics of these networks are determined by independent decision-makers, a solid understanding, control and optimization of such networked systems constitutes a major challenge with high socio-economic impact, requiring an inherently transdisciplinary approach. The aim of this Action is to address, at a European level, the research challenges that emerge from the interactions of strategically-minded and independent decision-makers that are embedded in large-scale distributed networks. In particular, this Action will focus on the following challenges:

- To provide accurate models for large-scale networks with strategically interacting entities.
- To develop efficient, low-complexity algorithms that can solve these models.
- To evaluate the performance and robustness of large-scale networks.
- To reverse-engineer the design tools required to control and optimize such systems.
- To develop game theoretic models for industrial applications in telecommunication and traffic networks.

All these issues are of high socio-economic value and involve the core competencies of a wide spectrum of researchers in computer science, economics and mathematics.

II) RELEVANCE AND TIMELINESS

Game theory is a discipline with high socio-economic impact. For example, the auctioning of spectrum licenses in 2000 for 3rd-generation mobile networks in Europe was designed by economists using a deep game theoretic analysis. As a result, the auctions in Germany and the UK led to revenue for the government of approximately 2 per cent of the GDP in these countries. Similarly, game theoretic concepts are nowadays used in the analysis of networked systems, such as the computation of equilibrium traffic flows in large-scale transportation networks, the prediction of content popularity in social networks and online services, and the analysis of resource allocation mechanisms in wireless communication networks. Since there are many applications from different fields exhibiting similar network structures (e.g., biological, technological and social networks), and each of these applications has field-specific characteristics, our action intends to bring together researchers from different fields of science, ranging from computer science, mathematics and economics. To name but a few instances of

this interdisciplinarity, the development of efficient - and efficiently implementable - algorithms and protocols for traffic management requires deep cooperation between network planners, computer scientists and game theorists. As another example, opportunistic spectrum access and the efficient allocation of spectrum resources is a key feature of future and emerging wireless networks, and the optimization of these attributes requires a firm game-theoretic footing in order to be applicable to large, decentralized wireless networks. With all this in mind, this Action will be the first European network where computer scientists, mathematicians and economists join forces on problems with significant technological and socio- economic impact (such as the design of distributed resource allocation protocols for next- generation mobile systems). Specifically, the scientific program will address four central topics:

- Algorithmic Theory for Games on Networks
- Learning in Large-Scale Distributed Networks
- Graph Games
- Stochastic Methods in Game Theory

In proposing to put together a unique intellectual platform for the efficient dissemination of research output in game theory across Europe, this Action provides a European platform for game theoretic research with a unified research vision, capable of proposing interdisciplinary solutions to important problems in economics, computer science and mathematics, in industry as well as in academia.

B) SPECIFIC OBJECTIVES

I) RESEARCH COORDINATION OBJECTIVES

The primary goal of GAMENET is to drive the European research in game theory, and the development of new tools for its industrial application.

Algorithmic understanding of large network games:

1. Improve algorithmic standards for the quantitative analysis of games on large networks.
2. Provide new polynomial-time algorithms for the analysis of graph games with stochastic transitions.
3. Develop a computational environment for high-frequency games with partial monitoring.
4. Provide accurate tracking algorithms for games with unpredictable variability.
5. Develop an algorithmic framework for evolutionary games on graphs.

The Implementation of Game-Theoretic algorithms in industry

6. Develop efficient and practical algorithms for resource allocation problems in 5G wireless communication networks.
7. Develop a portfolio of real-world applications for these algorithms in wireless networks.
8. Provide a software library for effective Congestion control to help traffic planners to reduce congestion, air pollution, and increase efficiency of road networks.
9. Identify the future needs of industry.

Fundamental Research on Games on large networks

10. Develop a new theory for continuous-time games.
11. Turn this theory into practical numerical algorithms for the quantitative analysis of continuous time games.
12. Identify classes of graph games which admit a polynomial-time algorithm for solving them.

II) CAPACITY-BUILDING OBJECTIVES

1. Create an excellent network of researchers in Europe with lasting collaboration beyond the lifetime the Action.
2. Transfer knowledge in terms of expertise, scientific tools and human resources across the disciplines and between academia and industry.
3. Establish an inclusive research community for game theoretic research to promote Early Career Investigators (ECIs) and increase their visibility.
4. Significantly improve the gender equality in the Action.
5. To achieve geographical and demographical diversity with special attention to gender balance and COST Inclusiveness Target countries, throughout the Action.
6. Prepare competitive EU researchers for a fruitful career in an international environment through intensive use of Short Term Scientific Missions (STM) and joint educational programs with industrial partners.
7. Maximise the job opportunities for PhD students and ECIs.
8. Disseminate the results of the Action activities to the scientific community and to the general public.

C) PROGRESS BEYOND THE STATE-OF-THE-ART AND INNOVATION POTENTIAL

I) DESCRIPTION OF THE STATE-OF-THE-ART

GAMENET will be organized in 4 Working Groups (WGs). The composition of each WG reflects the mix in the research objectives of the Action, including research on algorithms, application to industry, and fundamental methodological research. Cross-fertilization across the fields and bundling of expertise is the main goal of this specific architecture. The working groups are organized along the following themes:

WG1- Algorithmic Theory for Games on Networks. Efficient computation is a spinal backbone of modern society, including communication, transportation, production as well as services. In almost all domains, computation takes place in a networked system of interacting entities. Once these entities act on their own behalf, we are faced with the challenge to model, analyse, and anticipate the phenomenon of strategic behaviour. Even if an accurate model for strategic behaviour of interacting entities has been obtained, the crucial challenge to actually solve the model (e.g. to compute an equilibrium) remains. Polynomial time computation of the outcome of strategic behaviour and its computational complexity is the core issue addressed in the field of Algorithmic Game Theory. It builds upon the concepts and models developed at the intersection of Economics and Theoretical Computer Science and has lately become an influential field particularly in Computer Science. Recent progress in this field has led to disruptive breakthroughs, both in theory (e.g., the PPAD-hardness proof for computation of Nash equilibria) and practice (e.g., auction design for companies such as Google, Microsoft, Yahoo! and eBay). Algorithmic Game Theory is an important ingredient of what can be called Economic Engineering: by way of theoretical insights, and by using information and communication technology, the goal is to (optimally) engineer systems that anticipate on the interaction of economic agents for the better of society.

WG2- Learning in Large-Scale Distributed Networks. In the traditional approach to network analysis and design (traffic networks, data networks, etc.), the vast majority of models has focused on two limit cases: In the static regime, the attributes of the network are assumed effectively static and the system's analysis relies on techniques from optimization, game theory and (optimal) control. On the other hand, in the so-called stochastic regime, the network is assumed to evolve randomly following some stationary probability law, and the allocation of resources is optimized using tools from stochastic optimization and control. In modern networks, however (such as the Internet, cognitive radios and wireless networks), both assumptions fail because of factors that introduce unpredictable variability to the system (for instance, users going arbitrarily on- and off- line, non-random capacity fluctuations, etc.). As a

result, existing resource allocation schemes do not – in fact, cannot – apply in this setting because “optimum” target states no longer exist, either static or in the mean. In view of the above, we envision a drastic turn towards a flexible resource allocation paradigm (i.e. without any prior system knowledge) based on game theory, machine learning and the deployment of online optimization protocols at the network's decision-making level.

WG3- Graph Games. Graph games are a mathematical framework to analyse reactive systems. A reactive system interacts with an environment and it consists of several variables. Consider the example of a train-gate controller, where there is a variable for the gate position (say, open, closed, closing), and a variable to denote positions of trains (say, away, approaching, at gate, crossed, gone). A state of the system is a valuation to the variables, such as the gate being open and train being away, or a train is approaching and the gate is closing. In graph games vertices of the graph represent states of the reactive system, edges of the graph represent transition of the reactive systems, paths of the graph represent behaviours of the system, and different interacting agents represent the different players. A large class of computer systems interact with an environment (for example, a traffic-light controller needs to interact with the vehicles), or the system consists of multiple components. Each interacting component (or the system and the environment) is represented as a player, and game theory provides the correct framework to study the problems that arise in the formal analysis of reactive systems. The associated research problem is the algorithmic and computational complexity analysis of games on graphs. In deterministic reactive systems, these questions have been quite deeply studied. The significant theoretical achievements have resulted in several algorithms and satisfactory computational complexity results for deterministic graph games with respect to omega-regular objectives (omega- regular objectives can express all commonly used properties of reactive systems). These algorithms can be used in practice, such as, automatically deriving AMBA-Bus protocol, widely used in industries, and the game-theoretic algorithms are routinely used in correctness analysis of complex, safety-critical systems.

WG4- Stochastic Methods in Game Theory. Stochastic games comprise a general model for the study and analysis of dynamic interactions in economic and technological contexts. It includes the theory of repeated games, stopping games, differential games and mean-field games. Since its beginning, the main fields where repeated games are applied are economics, finance, biology, engineering and computer science, and it is impossible to overestimate the impact that the theory of stochastic games has had in these fields - as evidenced by the many game theorists that have been awarded the Nobel memorial prize in economics for their contributions to the theory of stochastic games. Recent advances in stochastic games include new computational tools, and approaches in continuous time, which are also the main tasks of this working group. Faced by the new applications and problems described in WGs 2 and 3, the role of this WG is to support the applications in these fields, by developing the rigorous mathematical foundations for the game problems arising therein.

II) PROGRESS BEYOND THE STATE-OF-THE-ART

This Action will improve upon the state-of-the-art in all the 4 subfields of game theory described in Section 1.3.1.

WG1 - Algorithmic Theory for Games on Networks. The computational aspects of game theory are fundamental to the advancements of the theory and its applicability. The first task of this WG is to introduce behavioural aspects into the research agenda of algorithmic game theory. In particular, this will be of key importance for the modelling of the evolution of dynamic networks, being either biological, technological or social networks. A second task treated in this WG is a novel computational approach to dynamic mechanism design and optimal mechanism design (i.e. revenue maximization of the designer). Emphasis will be made to the very complex question of optimal mechanism design with multiple goods. A third task of this WG is the development of new coordination mechanisms for resource allocation problems. As

a concrete industrial application, we will develop new coordination mechanisms for the design of traffic navigation systems. We will develop algorithms that will be released to the public in the form of a software library so that industry partners and city- and traffic planers can make use of it. Participants of this Action are in close contact with leading researchers at a leading producer of traffic, navigation and mapping products, which offers the unique possibility to bring solutions of the project into practice.

WG2 – Learning Dynamics in Large-Scale Distributed Networks. One of the main challenges in this context is that the study of game-theoretic learning algorithms has focused almost exclusively on static games with a finite number of actions and simple interaction structures. Here, the performance gap between a dynamic resource allocation policy and the optimum fixed policy (which, of course, can only be calculated with perfect knowledge of the system's evolution ahead of time) is quantified by the notion of regret. However, to achieve real-time performance gains in real distributed networks (such as the Internet), it is imperative to track the instantaneous optimum resource allocation policy, so we need to go beyond the standard framework of average regret minimization. This necessitates making a clean break with existing learning methodologies and comprises one of the main objectives of this Action. This will be a highly interdisciplinary theme were researchers from WG3 on Graph games combine their algorithmic expertise with experts from learning theory (WG2) and algorithmic game theory (WG4). Furthermore, in large-scale distributed networks, the unilateral minimization of an agent's regret does not guarantee the system's equilibration – especially in the presence of unpredictable temporal variabilities. Hence, in the presence of several decision-makers with competing, time-varying objectives, it is crucial to derive adaptive policies that are capable of following the system's equilibrium state as it evolves over time. Despite their many applications in telecommunications and computer science, the development of learning algorithms beyond this unilateral regime remains at an embryonic stage. In particular, the unilateral framework breaks down completely when decision-makers interact on a large dynamic network, so the situation calls for more sophisticated, online techniques that are provably capable of following a coordinated equilibrium system state. The tasks for this WG are the development of new methods for learning in games with continuous action spaces, and their robust extensions to games with time-varying payoffs. Given the immediate industrial applications of this approach, the theory developed in this WG will be developed in close collaboration with industrial partners from the telecommunications industry.

WG3 - Graph Games. The traditional formulation of graph games assumes deterministic transitions between the states of the system. In practical applications, this assumption is usually not satisfied. Instead an extension to stochastic transitions in the graph is needed in order to capture uncertainty and random perturbations. The departure from deterministic transitions, however, creates challenging open problems. An important task is to identify subclasses of stochastic games which admit deterministic sub-exponential time algorithms. While obtaining a polynomial-time algorithm for perfect-information stochastic games is a major and long-standing open question, obtaining deterministic sub-exponential time algorithms, even for subclasses, would be an important breakthrough. Finding special instances and algorithms is a research theme pursued together with members of the research team of WG4 in the first two years of the Action. The second task is to investigate evolutionary game dynamics from an algorithmic perspective. While the algorithmic problem of evolutionary games on graphs is computationally hard (PSPACE- complete), obtaining efficient algorithms for special cases (such as regular graphs) would be a major advancement in the area. Parallel to that, the third task is to develop scalable practical algorithms for multi-agent systems in uncertain environments. A key deliverable here will be to develop algorithms that work efficiently on some real-world examples.

WG4 - Stochastic Methods in Game Theory. Recent advances in stochastic game theory have been made in the mathematical modelling and analysis of games in continuous time, in their relation to their discrete-time counterparts, and in the development of computational methods

for games. While most of the mathematical literature focused on zero-sum games, applications are usually non-zero sum and involve large numbers of players (acting in a networked system) having only partial monitoring about the relevant variables (e.g., limited observability of the other players' routing strategy in data networks). Hence, new methods for the mathematical analysis of non-zero sum stochastic continuous-time games have to be developed. The development of new analytic as well as numerical tools for such problems is one key task of this WG and what correspond to a major theoretical breakthrough in the field. A second goal is the development of a theory of dynamic network congestion games under uncertainty, which will allow us to study various real-life phenomena, like accidents and immigration. This will require tools that allow to simultaneously deal with uncertainty over time and space, a problem that the present theory of stochastic games does not address. There are also new challenges stochastic game theory faces in the field of reactive systems and graph games. Researchers in this field seek to identify classes of stochastic games for which equilibria can be found by efficient and robust algorithms. The identification of favourable instances of stochastic games admitting deterministic sub-exponential time algorithms is another major task of this WG, tackled together with WG3. This line of research is another major scientific breakthrough in the field.

III) INNOVATION IN TACKLING THE CHALLENGE

- Cross-disciplinary working groups: The new challenges faced by game theorists, as described above, require an interdisciplinary approach. GAMENET aims to launch new interdisciplinary collaborations in order to tackle these questions.
- Improving visibility: Most developments in game theory are only visible to small groups of researchers. This is mainly due to the disciplinary boundaries of the various fields (i.e. economics, computer science and applied mathematics). This Action will be the worldwide focal point for game theoretic expertise and serve to shatter cross-disciplinary boundaries.
- Integrated toolkit: The Action intends to develop an integrated toolkit for the analysis of evolutionary game dynamics (GANNT 4a) on graphs, downloadable freely from the Action's webpage.
- Industrial collaborations: GAMENET's research activities will be of great interest to several industrial stakeholders, including a producer of networking and telecommunications equipment, a European telecom company and a leading producer of traffic, navigation and mapping products. Our collaboration will span from academic training in the form of joint Post-Doctoral fellowships, ongoing research grants, and a concrete patenting strategy, which will serve as a motivating element for industrial and academic partners to guarantee commitment and devotion to the success of the Action. We also intend to take advantage of our industrial partners' marketing expertise to actively seek business exploitation opportunities for GAMENET's theoretical and algorithmic advances. Feedback between industry and academia: To guarantee optimal collaboration with the above mentioned industrial partners, we intend to involve key researchers from the industrial R&D departments as Action members. Besides the extensive joint training and research activities, this will guarantee fruitful interaction between industrial and academic partners in each activity of GAMENET. Furthermore, we plan two industry-academia workshops and produce a white paper describing the future industrial needs of game-theoretic research. This should lay the foundations for future collaborations, extending beyond the lifetime of this Action.
- Software Library for Traffic planning: One key deliverable of this Action is to design algorithms for traffic planning in large networks. These algorithms will be released to the public domain through the Action's website in the form of a publicly accessible software library. The software library is intended to be a new decision support instrument for policy makers and industrial partners in traffic networks.

D) ADDED VALUE OF NETWORKING

I) IN RELATION TO THE CHALLENGE

GAMENET's proposers cover most of the knowledge necessary for the success of the Action. The most relevant experts on game theoretic research in economics, mathematics and computer science are among the proposers. Such a wide collaboration in terms of skills and geographic involvement will be the only way to leverage on scattered results to attain the best worldwide results for the academic and industrial analysis of large network games.

- The strengthened cross-disciplinary communication between mathematics, computer science and economics will allow to optimise the significance of the results.
- The network will provide the framework for comparing results and approaches obtained in the different communities.
- The close collaboration between scientists from the different disciplines will guarantee that theoretical and industry-relevant results are published in a format most suitable for effective dissemination.
- The inclusion of COST NNC and COST IPC in the Action will strengthen the leading role of Europe in the fundamental research in game theory and will pave the way for a long term community that will survive the end of this Action.
- Participation in GAMENET will enhance chances of finding jobs for young scientists through the created network and cutting-edge academic and industrial training.
- The attention to COST Inclusiveness Countries (ITC) will fill the gap with the rest of the EU community.
- Our gender balance policy will provide further visibility to top female researchers in the field.

II) IN RELATION TO EXISTING EFFORTS AT EUROPEAN AND/OR INTERNATIONAL LEVEL

This Action is unique in its scope of research topics and also in its internal composition, where we actively sought to strike the best possible balance between the main fields of science involved in GAMENET's core research objectives. At the current state of the proposal, the network reflects the needs and complementary viewpoints of mathematics, computer science and economics. At the European level, the most similar Action is COST Action IC1205 "Computational Social Choice" (2012-2016). This Action also combines game theory with computer science, but is focused on aspects of social choice theory and cooperative game theory. Both are traditionally static theories. It does neither emphasize dynamic strategic interactions that much as the proposed Action, nor the aim to be really a network representing the broadness of game theoretic research as it is done nowadays. Beside this Action, there are not many comparable initiatives. COST Action IC0602 on Algorithmic Decision theory (2006-2011) was related to this Action, but only treated the single player case. We instead are interested in the multi-player case. Vaguely related to this Action is also COST Action CA15109 European Cooperation for Statistics of Network Data Science (COSTNET). This action however does not fully address strategic aspects of network analysis.

2) IMPACT

A) EXPECTED IMPACT

I) SHORT-TERM AND LONG-TERM SCIENTIFIC, TECHNOLOGICAL, AND/OR SOCIOECONOMIC IMPACTS

1. Scientific Impact:

- Develop new algorithmic frameworks for the analysis of large network games and mechanism design.

- Develop deterministic sub-exponential-time algorithms for graph games, and classify games where polynomial-time algorithms can be defined.
- Develop a new theory for continuous-time games, and turn this theory into an applicable quantitative framework.
- Produce a deeper understanding of strategic interactions at high-frequency with partial monitoring.
- Develop learning dynamics designed for tracking equilibria in games with unpredictable variability.
- Introduce behavioural aspects into the field of Algorithmic Mechanism Design.

2. Technological Impact

- Develop new resource allocation mechanism for 5G wireless communication networks based on game-theoretic learning.
- Bringing the expertise of engineers working at R&D departments of large telecommunication networks into the academic arena of game theory.
- Develop a new traffic planning software toolkit for effective congestion control.
- Provide state-of-the art solvers for games applied to the analysis of evolutionary dynamics on graphs and reactive systems.
- Provide polynomial time algorithms for reactive systems.

3. Socio-economic Impact

- The creation of a multidisciplinary, functional and cohesive European network for game theory, overcoming the current fragmentation, to remain active beyond this Action.
- Strengthen Europe's leadership in fundamental research in game theory, thanks to the creation of a strong international community.
- Educate highly-motivated students and Post-docs to leading roles in research in industry and academia, capable to working in a competitive international environment.
- Create additional opportunities for GAMENET members, their students and Post-docs, to further boost their career.
- Increase the visibility of individual institutions generating synergies and multidisciplinary collaborations to foster innovation in the field.

B) MEASURES TO MAXIMISE IMPACT

I) PLAN FOR INVOLVING THE MOST RELEVANT STAKEHOLDERS

The proponents of this Action comprise experts from economics, mathematics and computer science. They will use their personal contacts as well as collaboration meetings to recruit additional contributors, also from Inclusiveness Target Countries. We seek for involvement of experts from the industrial partners in the Action activities as well.

Young Talents' promotion will be achieved by putting them in close contact with leading groups in game theory, granting them visibility in the scientific community, exposing them to overviews of most important results in the areas, and supporting university internationalisation programs via the use of STSMs. This will be accomplished through scientific exchanges between ECIs, senior experts, and joint PhD supervisions. We will organise three summer schools, an ECI meeting, and grant sizable room for young researchers to present and discuss their results at the Action meetings. To maximise the success of ECIs' future careers, the Action will also deliver a platform, within its website, to gather job opportunities in the field and a database of job offers and available candidates, to be subscribed by PhDs and Post-docs.

The Action has already attracted a substantial number of stakeholders from the scientific community as part of the network. These stakeholders' interests span all the disciplines

touched by this Action, ranging from game theory and optimisation to operations research and engineering. This guarantees that the aim of creating a strong and vibrant community will be fulfilled.

GAMENET will proactively involve industrial stakeholders as a result of the extensive dissemination plan. Conversely, industrial partners have already expressed their interest to participate in the research activities of GAMENET. Members of GAMENET have signed research contracts with a producer of networking and telecommunications equipment, and have agreed on joint hiring of Post-Docs working on subjects that are closely aligned with GAMENET's objectives. We intend to hold regular meetings with leading representatives of our industrial partners. In conjunction with making progress towards GAMENET's research objectives, these meetings will also serve to steer GAMENET's theoretical objectives, and will finally lead to a patenting strategy involving the researchers of GAMENET.

II) DISSEMINATION AND/OR EXPLOITATION PLAN

- Action website - The Action will maintain a public website to coordinate and bundle all dissemination activities. All events planned by the Action will be announced there. Teaching materials, as well as research reports, developed software, job opportunities, and publications stemming from the Action will be made available for download on this website. External research reports and publications that are of interest to the members of the Action will be linked from this website. Additionally, STSM reports will be published via the website. (GANTT 1a and b)
- Publications - All members of the Action will publish their results in high profile peer-reviewed journals and conference proceedings. (GANTT 4b)
- Workshop - The Action will organize thematic workshops (WS) each year, co-located with the Action meeting. The WS will be an open event, accompanied with discussion sessions and panels boosting the communication between speakers and the audience. (GANTT 2f)
- Summer Schools - We will organize three summer schools in order to attract new young researchers. (GANTT 2b).
- ECI meetings - We will organize two ECI meetings, where the aim is to exchange results on one's peers only (GANTT 2a).
- White papers - Each working group leader will produce one white paper after the first two years to give an overview on the current and projected activities within the Action. (GANTT 5b-e)
- Meetings with Industrial players - To ensure participation of important industrial stakeholders, we will organize several meetings with relevant players from industry. These meetings will serve to foster concrete collaborations between academic research and industrial practitioners, with the clear aim of channelling GAMENET's theoretical achievements to problems of high practical relevance (as identified by our industrial partners). (GANTT 2e)
- Industrial Needs - Those WGs with industrial applications will produce one Industrial and Societal Needs White paper. With these white papers, we will give a comprehensive account of the modern needs of industrial players and users of game theory. (GANTT 5a)
- Final Report: A Final report produced jointly by all four WGs will give a compact summary over the activities of this Action. (GANTT 5f)
- Outreach activities - Action members will present their work at major conferences in their fields, and use the networks' expertise to prepare joint Grant applications in the Horizon 2020 framework. (GANTT 4c)

C) POTENTIAL FOR INNOVATION VERSUS RISK LEVEL

I) POTENTIAL FOR SCIENTIFIC, TECHNOLOGICAL AND/OR SOCIOECONOMIC INNOVATION BREAKTHROUGHS

The Action has identified a number of scientific and technological challenges of various degrees of complexity. These goals are rooted both in the fundamentals of game theoretic research, as well as in the industrial applications of it. The minimal goal of the work proposed is to foster the industrial dimension of game-theoretic learning dynamics in wireless networks. This goal would represent a significant technological and socio-economic impact in itself and can be achieved even if some of the other work packages cannot be completed. In the best case, the studies proposed here will discover fundamental breakthroughs in the algorithmic and mathematical theory of games, which on top will serve for an even more effective treatment of the described applications of network games in industry. This would represent a major breakthrough at the scientific, technological and socio-economic level. In this case, the network representing GAMENET will be of particular importance to reap maximal scientific benefit, as the close collaboration of the relevant experts in economics, mathematics, engineering and computer science will be essential.

3) IMPLEMENTATION

A) DESCRIPTION OF THE WORK PLAN

I) DESCRIPTION OF WORKING GROUPS

The main breakthroughs of WG1 are to advance our knowledge of the algorithmic aspects of network games and mechanism design problems on networks, as they arise in congestion control and traffic planning problems in transportation networks. The main innovations of this WG are:

1. To introduce behavioural aspects into the field of algorithmic mechanism design.
2. To understand multi-dimensional mechanism design on networks.
3. Develop a software library for traffic planning, in collaboration with partners from industry.
4. Develop new coordination mechanism for network resource allocation.

These goals are going to be achieved by closed interaction with researchers of WG2 and WG4.

WG1: Algorithmic theory of network games			
Main aim	Develop an algorithmic theory of decision making for mechanism design and coordination mechanism design problems in the context of network applications. This work package will resort to classical algorithm design paradigms such as polynomial time approximation algorithms, as well as complexity theoretic lower bounds for the resulting optimization problems.		
Tasks	▪ Behavioural aspects of mechanism design with social network interaction ▪ Algorithmic mechanism design (AMD) with multiple parameters ▪ Coordination mechanisms for network resource allocation		
Deliverables	No.	Title	M.
	D1.1	Behavioural strategies and embedding into social networks | Incorporate bounded rationality and social network structure in AMD.	M12
	D1.2	Year 1 workshop | Discussion of models in AMD with social interaction	M12
	D1.3	Multi-dimensional mechanism design | AMD coping with multi-parameter agents	M16
	D1.4	Year 2 workshop | Meeting with industrial telecommunications partners	M28
	D1.5	Coordination mechanism design | Algorithms and Complexity of optimal coordination mechanisms in network resource allocation	M30

WG1: Algorithmic theory of network games			
	D1.6	Year 3 workshop | Coordination mechanisms; Applications to traffic networks	M36
	D1.7	Industrial needs white paper | Contribution to Industrial Needs white paper; Industrial applications of AGT; Future outlook	M36
	D1.8	Software library | Presentation of a software library for traffic navigation and coordination systems	M48
	D1.9	Year 4 workshop | Contribution of WG1 to the Y4 workshop	M48
	D1.10	Final report input | Contribution of WG1 to GAMENET's final report	M48
Milestones	Understanding AMD on social networks AMD with multi-parameter agents Algorithms for coordinating selfish players in large networks		Y1:Y2 Y2:Y3 Y3:Y4

The targeted breakthrough of WG2 will be to develop highly adaptive learning algorithms that are provably capable of tracking unpredictable changes in the decision makers' environment by harnessing the fusion of game-theoretic and online optimisation techniques. The main tasks are:

1. To develop an algorithmic framework for learning in games with continuous action sets, using recent advances in mathematical optimization and the theory of variational inequalities.
2. To derive adaptive learning policies that are able to track the evolving equilibrium of a time varying multi-agent system (such as a dynamic wireless network). This task will rely on developing a toolbox for solving online variational inequalities by combining results from operator theory and non-stationary online optimization.
3. To develop learning methods for stochastic games that model situations where the decision makers are not completely oblivious to the state of the network (as in commuting with the help of a GPS device, similar to some scenarios considered in WG1)

WG2: Learning in Distributed Large-Scale Networks			
Main aim	Design of efficient game-theoretic learning algorithms with a view towards their implementation in next-generation communication networks. Support and collaborate with industrial partners in the design of efficient resource allocation schemes based on the learning dynamics.		
Tasks	▪ Learning in games with continuous action spaces ▪ Real-time equilibrium tracking in dynamic networks ▪ Adaptive dynamics in stochastic games		
Deliverables	No.	Title	M.
	D2.1	Learning in static games | Presentation of new game-theoretic learning algorithms	M10
	D2.2	Industrial needs workshop | Meeting with industrial telecommunications players	M10
	D2.3	Year 1 workshop | Contribution of WG2 to the Y1 workshop	M12
	D2.4	Learning for network-driven applications | Presentation of network resource allocation algorithms	M16
	D2.5	Year 2 workshop | Contribution of WG2 to the Y2 workshop	M24
	D2.6	Learning in dynamic games | Learning in time-varying environments	M30
	D2.7	Year 3 workshop | Contribution of WG2 to the Y3 workshop	M36

WG2: Learning in Distributed Large-Scale Networks			
	D2.8	Industrial needs white paper | Applications of learning in wireless communications	M36
	D2.9	Simulation platform for learning dynamics | Simulator for learning algorithms and dynamics	M48
	D2.10	Year 4 workshop | Contribution of WG2 to the Y4 workshop	M48
	D2.11	Final report input | Contribution of WG2 to GAMENET's final report	M48
Milestones	Novel game-theoretic learning algorithms Performance limits of learning in networks Protocols for resource allocation in data networks		Y1:Y2 Y2:Y3 Y3:Y4

The targeted breakthroughs for WG3 are to advance our knowledge on the algorithmic and computational complexity questions for various classes of graph games, which provide a fundamental model in computer science, logic and automata theory. Some of the major open challenges are as follows:

1. Can the computational problem for perfect-information deterministic mean-payoff games can be solved in polynomial time?
2. Can the computational problem for perfect-information stochastic reachability games be solved in polynomial time?

While the above answers will be major breakthroughs, there are several important intermediate steps. For example, even obtaining deterministic subexponential-time algorithms for the above problems will be huge results. The interactions with stochastic game theorists in WG4 will lead to new algorithmic insights. The insights will help us to design better algorithms, which will be either important breakthroughs, or at the least important advances in the fields.

WG3: Graph Games			
Main aim	Design of efficient algorithmic for graph games with stochastic transitions, evolutionary games, and multi-agent systems, with a view towards their implementation for formal analysis of reactive systems.		
Tasks	▪ Algorithms for graph games with stochastic transitions ▪ Algorithmic perspectives of evolutionary games on graphs ▪ Algorithmic approaches for multi-agent systems		
Deliverables	No.	Title	M.
	D3.1	Stochastic transitions | Presentation of graph games with probabilistic transitions	M10
	D3.2	Year 1 workshop | Contribution of WG3 to the year 1 workshop	M12
	D3.3	Evolutionary games on graphs | Algorithmic aspects of Evolutionary Graph Games	M20
	D3.4	Year 2 workshop | Contribution of WG3 to the year 2 workshop	M24
	D3.5	Multi-agent systems | Graph games with many players	M32
	D3.6	Year 3 workshop | Contribution of WG3 to the year 3 workshop	M36
	D3.7	Case studies | Application of algorithms in analysis of reactive systems, protocol design	M42

WG3: Graph Games			
	D3.8	Year 4 workshop | Contribution of WG3 to the year 4 workshop	M48
	D3.9	Final report input | Contribution of WG3 to GAMENET's final report	M48
Milestones	▪ Novel algorithms for stochastic graph games ▪ New algorithms for evolutionary graph games ▪ Practical algorithmic approaches for multi-agent systems		Y1:Y2 Y2:Y3 Y3:Y4

The main breakthroughs of WG4 are to advance our understandings of the fundamentals of important classes of repeated and stochastic games, which are fundamental models in economics, operations research and computer science. Some of the major open challenges are:

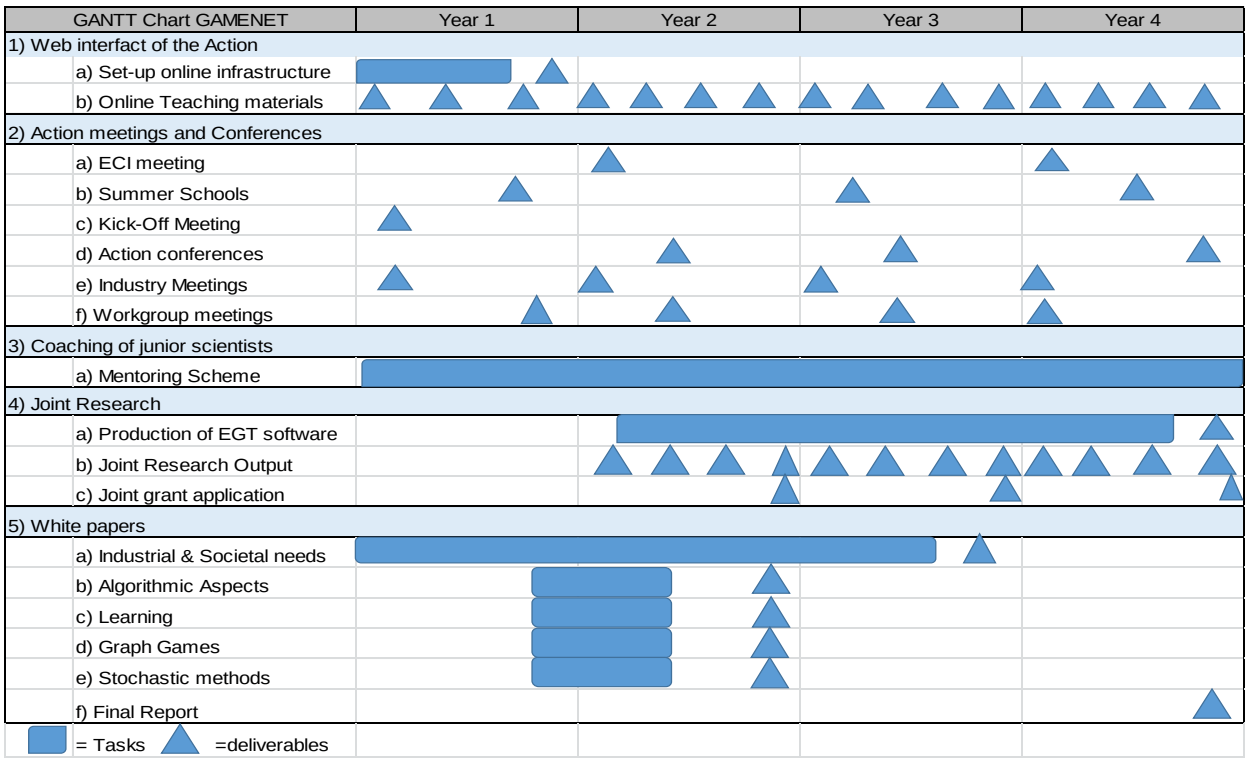
1. Develop a theory of continuous time games, and provide new tools for their qualitative and quantitative study.
2. Develop a theory for dynamic network congestion games.
3. Identify classes of stochastic games which admit polynomial-time algorithms.

In solving these challenges, the researchers from WG4 will closely interact with members of all the other WGs.

WG4: Stochastic Methods in Game Theory			
Main aim	Develop the foundations for a new theory of games played in continuous time. Develop a theory for dynamic network congestion games with uncertainty. Develop numerical algorithms for such games. Identify favourable instances of stochastic games admitting polynomial-time algorithms.		
Tasks	▪ Develop a mathematical theory for continuous-time games with partial monitoring. ▪ Develop a theory for dynamic network congestion games with uncertainty. ▪ Computational framework for identifying sets of equilibrium payoffs. ▪ Identification of favourable stochastic games admitting efficient algorithmic solvers.		
Deliverables	No.	Title	M.
	D4.1	Continuous-time repeated games | Framework for detecting and computing equilibrium payoff sets	M6
	D4.2	Numerical Approximations | Algorithms to compute equilibrium payoffs of continuous-time games	M10
	D4.3	Year 1 workshop | Contribution of WG4 to the Y1 workshop	M12
	D4.4	Algorithms for stochastic games | Algorithms for graph games with random transitions	M16
	D4.5	Year 2 workshop | Contribution of WG4 to the Y2 workshop	M24
	D4.6	Dynamic network congestion games | Development of theory of dynamic network congestion games	M30
	D4.7	Continuous-time stochastic games | Develop a theory of regime-switching games with partial monitoring	M36
	D4.8	Year 3 workshop | Contribution of WG2 to the Y3 workshop	M36
	D4.9	White paper | Description of the state-of-affairs of this WG	M36

WG4: Stochastic Methods in Game Theory			
	D4.10	Algorithms for stochastic games | Develop numerical methods for stochastic games	M40
	D4.11	Year 4 workshop | Contribution of WG4 to the Y4 workshop	M48
	D4.12	Final report input | Contribution of WG4 to GAMENET's final report	M48
Milestones	▪ New methods for continuous-time game theory ▪ Numerical methods for the computation of equilibrium payoff sets ▪ Algorithms for stochastic games/Graph Games ▪ Dynamic network congestion games.		Y1:Y2 Y2:Y3 Y3:Y4 Y3:Y4

II) GANTT DIAGRAM



III) RISK AND CONTINGENCY PLANS

The MC chair together with the WG leaders will closely monitor the progress of the work to identify and mitigate the risks to the success of GAMENET in a timely manner. This approach will ensure that in addition to the risks, the Action is well prepared to unforeseen circumstances. The major risks are listed in the following tables.

External Risk	Probability	Impact	Mitigating action
High-complexity of research goals	Medium	High	This risk might be caused by unexpected problems arising while working on the problems. To minimize this risk, proper cooperation of the Action Members will be fostered via regular meetings, STSMs and reports to the WG conveners.

Results not up-to-date	Low	High	The leading experts of the fields are part of GAMENET. This ensures that the research questions and methods are at the state-of-the-art, and beyond. Our dissemination and outreach activities will guarantee that this will remain throughout the lifetime of this Action, and beyond.
Funding Risks	Low	Medium	GAMENET members will actively take part in funding applications in their countries and at the European Level in the framework of Horizon 2020, using the work within this Action to support the importance of game theory
Internal Risks	**Probability**	**Impact**	**Mitigating Action**
Lack of involvement of Action members	Moderate	Low	The network is already well-staffed with relevant experts to the point where no single member is essential to the Action. A replacement will be elected or appointed for management roles.
Difficulty in involving ECI, ITC in the Action, or in gender balancing	Low	Moderate	Targeted campaigns to enrich the Action participation, careful location planning of internal meetings.
Delay in completion of industrial applications	Moderate	Moderate	Members of the Action have signed research contracts with the industrial partners. In case of unanticipated delays, the MC will support important parts by granting STSMs and Research meetings.
Delay in implementation of novel analysis techniques	Moderate	Moderate	The expertise of the network, together with a careful comparison with existing approaches, will guide the development of new tools.

B) MANAGEMENT STRUCTURES AND PROCEDURES

The organization of GAMENET will follow COST rules. The Action will be governed by a Management Committee (MC), consisting of nationally nominated experts. The MC Chair and Vice-Chair will be elected during the 1st MC meeting and will coordinate all research activities. A wide participation in leadership positions will be ensured for ECIs, women as well as representatives from COST ITC. Each WG will be coordinated by a WG Leader and a Vice-Leader, elected during the kick-off meeting. WG Leaders are responsible for the coherence of the scientific work and the completion of specific deliverables and milestones. The MC will be supported by the Core Group (CG), consisting of the Chair, Vice-chair, a STSM Coordinator, and the WG chairs. The CG manages the day-to-day operations of the Action, monitors milestones and prepares documents and decisions for the MC, including a financial plan to adequately share the resources within the Action budget. In order to guarantee visibility of all activities in the Action, minutes will be timely released by the MC. The CG is also responsible for guaranteeing the interaction with and participation of the industrial partners.

C) NETWORK AS A WHOLE

The core expertise of the Proposers is concentrated around the fields Computer and Information Sciences, Economics & Business and Mathematics. This is the perfect mix for reaching the targeted goals. The network of proposers includes the leading European experts of this field and is truly unique not only in terms of intellectual diversity but also in geographic dispersion. It includes many award-winning scientists and the participants are in close contact with industrial partners, guaranteeing that the impact of GAMENET is not only restricted to academia.